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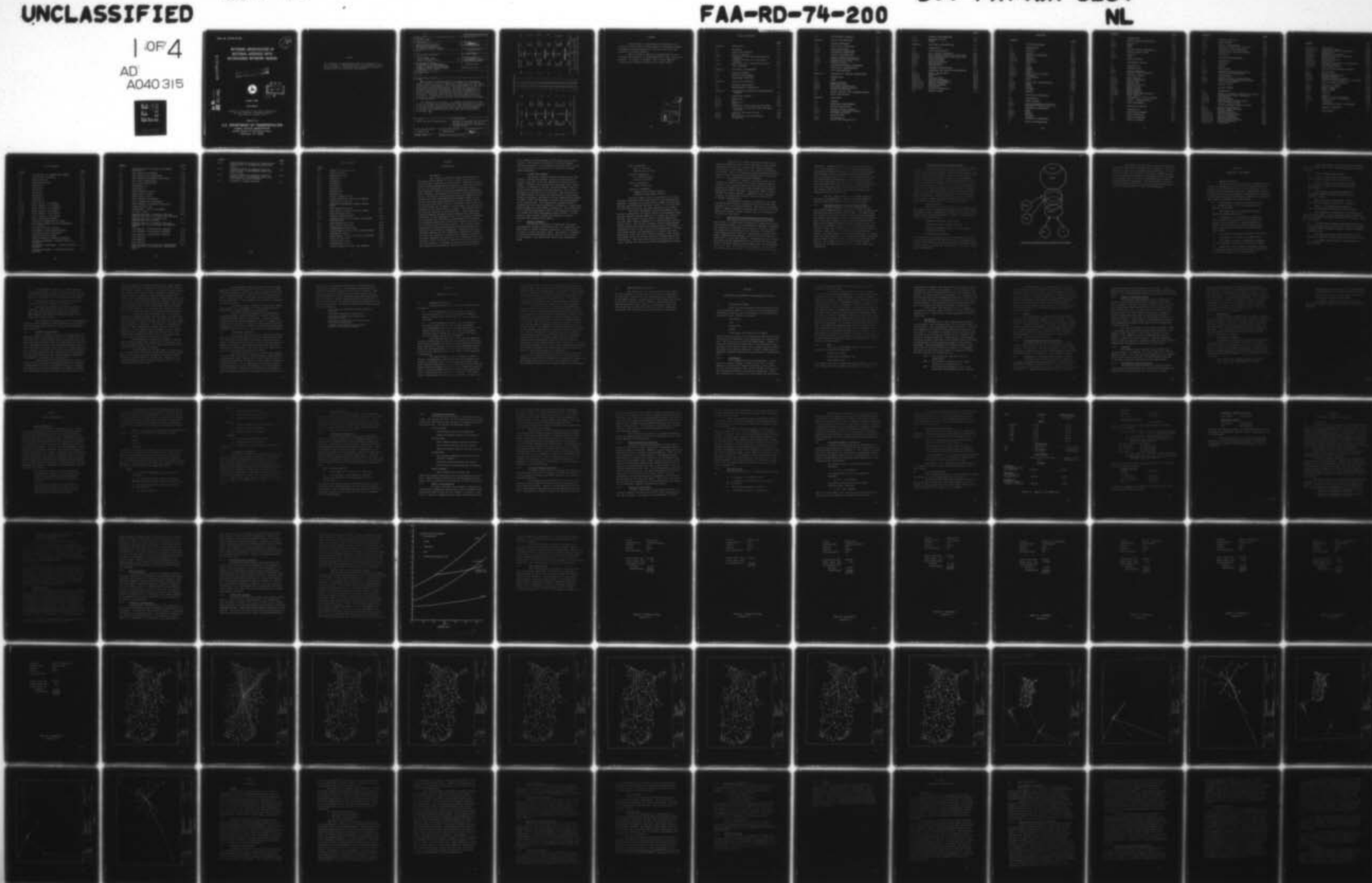

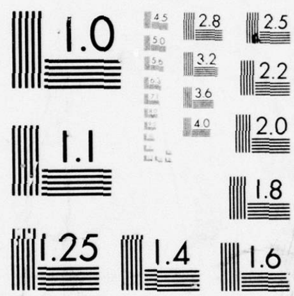

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16. Abstract

The currently proposed National Airspace Data Interchange Network (NADIN) is to be a common user network to serve FAA data communication requirements. The initial development of the network must be oriented towards improving existing services as well as accommodating future requirements. The FAA has suggested the Service B network and the Aeronautical Fixed Telecommunications Network (AFTN) as two existing services whose integration is technically feasible, operationally attractive and financially beneficial. In particular, the need for improvement of the two services is urgent since the current load on the existing networks is near saturation.

The purpose of this study is to examine the operational and technical feasibility of achieving the above objectives by developing an integrated network architecture. The study has resulted in a proposed network architecture which satisfies the objectives of Service B and AFTN and serves as a base for further NADIN development.

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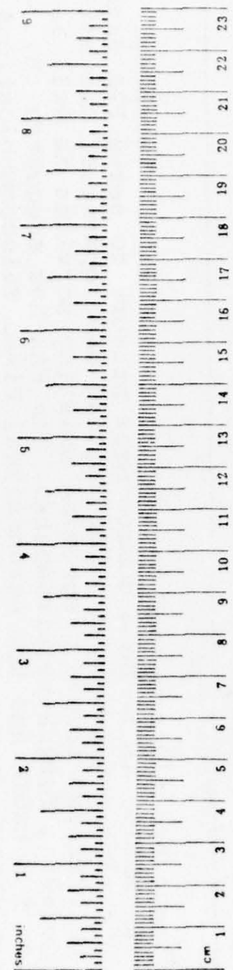
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

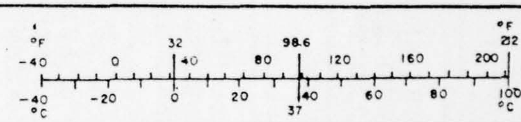
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The currently proposed National Airspace Data Interchange Network (NADIN) is to be a common user network to serve FAA data communication requirements. Although the NADIN concept extends beyond existing services in scope and function, the initial development of the network must be oriented towards improving existing services as needed where technologically feasible, operationally attractive, and financially beneficial. The FAA has identified the Service B network and the Aeronautical Fixed Telecommunications Network (AFTN) as two existing services whose integration is most likely to satisfy the above objectives as well as establish a kernel for further development of the NADIN. In particular, the need for improvement of the two services is urgent. The current load on the existing networks is near saturation. Load projections indicate complete saturation and, consequently, intolerable performance in the immediate future. The historical procedure for prolonging the satisfactory performance of the networks by introducing additional circuits has reached a point of limited effectiveness and immense expense. The networks appear operationally similar and technology appears available for achieving cost-effective integration. Because the Service B and AFTN networks are well established, operational, highly utilized, and represent a significant investment in dollars and human resources for operation, their improvement must come through a smooth evolution of operational procedures and hardware transitions. The purpose of this study is to examine the operational and technical feasibility of achieving the

above objectives by developing an integrated network architecture. The study has resulted in a proposed network architecture which not only satisfies the objectives for Service B and AFTN, but also serves as a kernel for further NADIN development.

1.2 SYSTEMS AND CONCEPTS

The message transfer networks operated by the FAA present a complex and somewhat confusing configuration of multiple nets that create the appearance of having grown at random. Actually, the networks were developed over a period of years in response to rapidly increasing demand, thus providing little opportunity for consolidation. Two of these networks are the subject of this study: AFTN and Service B. The NADIN concept is a result of FAA efforts to consolidate planning, operation, and control of data communication systems in order to meet the challenge of rapidly increasing demand in an effective way. The international message transfer networks have also been recognized as increasing in complexity while decreasing in efficiency; consequently, the International Civil Aviation Organization (ICAO) is developing the concept of a Common ICAO Data Interchange Network (CIDIN). In this section, each of these systems and concepts is briefly described and related to the others.

1.2.1 Service B Network

The Service B system is a common user low speed teletypewriter network used primarily for the transfer of the major share of flight planning information. It also serves a variety of other functional needs. The network is composed of several sub-networks described in terms of the circuits in the subnets. The subnets and circuits are categorized below:

Area B Subnetwork

Area B Circuits

Supplemental Circuits

Utility B Subnetwork

Air Carrier Circuits

Military Circuits

Center B Subnetwork

Center B Circuits

Computer B Subnetwork

Computer B Low Speed Circuits

Computer B High Speed Circuits

The most common circuit in Service B is a 75 bps (100 wpm) multipoint line connecting Model 28 teletypewriter terminals. Although the circuits have a common line protocol, they may serve different functional needs. It is on the basis of these differences that the above categories are formed.

The Area B subnetwork forms the backbone of the Service B System with the primary mission of exchanging flight planning messages between domestic air traffic facilities of the FAA. The network is also used to transfer administrative and other types of messages on a time-available and precedence basis. The Service B network, serving approximately 500 FAA facilities, consists of approximately 36 multipoint send/receive (S/R) 75 bps circuits interconnected by a 750 bps high speed circuit, and approximately 4 receive only (R/O) multipoint 75 bps circuits similarly attached to the 750 bps high speed circuit to relieve the heavy traffic load on the S/R circuits. The basic S/R circuits are called Area B circuits, and the R/O circuits are called supplemental circuits.

The Utility B subnet is used to transfer military and commercial carrier IFR flight plans to the center responsible for the area in which the flight originates. The circuits in the subnet are 75 bps (100 wpm) half-duplex facilities. They are intended to provide stations which have frequent daily insertions of IFR flight plans a direct connection to the responsible NAS 9020 computer.

The Center B network is primarily used for the exchange of flight movement and control messages normally related to IFR flights between the areas controlled by the conterminous ARTCCs and the Systems Command Center-Airport Reservations Office (SCC-ARO). Serving all ARTCCs and the SCC-ARO the Center B subnet is composed of five (100 wpm) circuits, interconnected through the DS 714 AFTN switch at NATCOM in Kansas City.

The Computer B network is composed of low speed and medium speed circuits interconnecting all the NAS 9020 computers on a point-to-point basis. The network is intended only for computer-computer communications, is not part of the common user message transfer system, and is not included in the scope of this study.

1.2.2 Aeronautical Fixed Telecommunications Network

The Aeronautical Fixed Telecommunications Network (AFTN) is a world wide teletypewriter communications system intended primarily for the exchange of messages concerning the safety of air navigation and regular, efficient, economical operation of international air services. The AFTN provides communications service for international aircraft movements, administrative messages, and meteorological data between the U. S. and ICAO nations. The present portion of AFTN for which FAA has responsibilities is divided into two major areas,- the North Atlantic and Caribbean Area and the Alaskan and Pacific Area; each being quite different in organization. The Alaskan and Pacific Area is served by multiple switching

centers at Anchorage and Honolulu. These centers operate in a fully automatic mode. In 1970, the FAA replaced the manual switching centers associated with the North Atlantic and Caribbean Area by an automated central distribution center at Kansas City, Missouri. Its function is the relay of international meteorological and aeronautical traffic which was originally performed at each of four locations: New York, Miami, San Juan, and Balboa. These four locations have now become hubs which feed the Kansas City center. The Honolulu IATSC has been converted to the same type of hubbed operation as Kansas city.

The most common terminal in the AFTN network is the Model 28 teletypewriter. There is a large number of both point-to-point circuits and multipoint circuits.

1.2.3 National Airspace Data Interchange Network

The NADIN concept is aimed at meeting the new and evolving communications requirements of the upgraded third generation National Airspace System (NAS). Included within the concept are the data transfer communication requirements for central flow control, modernized Flight Service Stations (FSS), and those elements of the terminal and enroute NAS dealing with ground-to-ground transfer of digital data. The NADIN is a conceptual framework for integrated data communications in FAA. The integration is on the levels of planning, operation, and control. It does not preclude dedicated systems, but rather denotes a coherent perspective. A natural result of such integration is an awareness of where facilities may be effectively shared and the ability to institute such sharing. This study, with its proposed common network architecture for AFTN and Service B, is a step toward such integration.

1.2.4 Common ICAO Data Interchange Network

The CIDIN concept is that of a high level, packet switching, international network serving the exchange of flight related messages between the ICAO member states. Standards and Recommended Practices (SARPS) for CIDIN are currently being developed by the Automatic Data Interchange Systems (ADIS) Panel of ICAO. Major message switching centers in the NADIN are envisioned as functioning also as the CIDIN centers operated by the United States. The interrelation of the systems and concepts described above is shown in Figure 1-1. As portrayed in the figure, the result of this study is a proposed network architecture that satisfies the basic objectives for improving AFTN and Service B, and will serve well as a kernel for further NADIN development. The architecture is referred to in this report as NADIN.

1.3 STUDY STRUCTURE

The goal for this study has been to develop a network architecture to satisfy FAA message transfer requirements (throughput, delay, reliability, economics) as defined by projected Service B and AFTN demands. Pursuit of the goal was guided by the objectives of:

Continuous operation transitions,

Consistency with the NADIN concepts,

Economic evolution from the existing system to eventual system,

Consistency with CIDIN.

The structure of the study was first to determine the operational requirements for the AFTN and Service B networks, then appraise the feasibility of satisfying these requirements with a common network architecture, and finally to develop a recommended architecture.

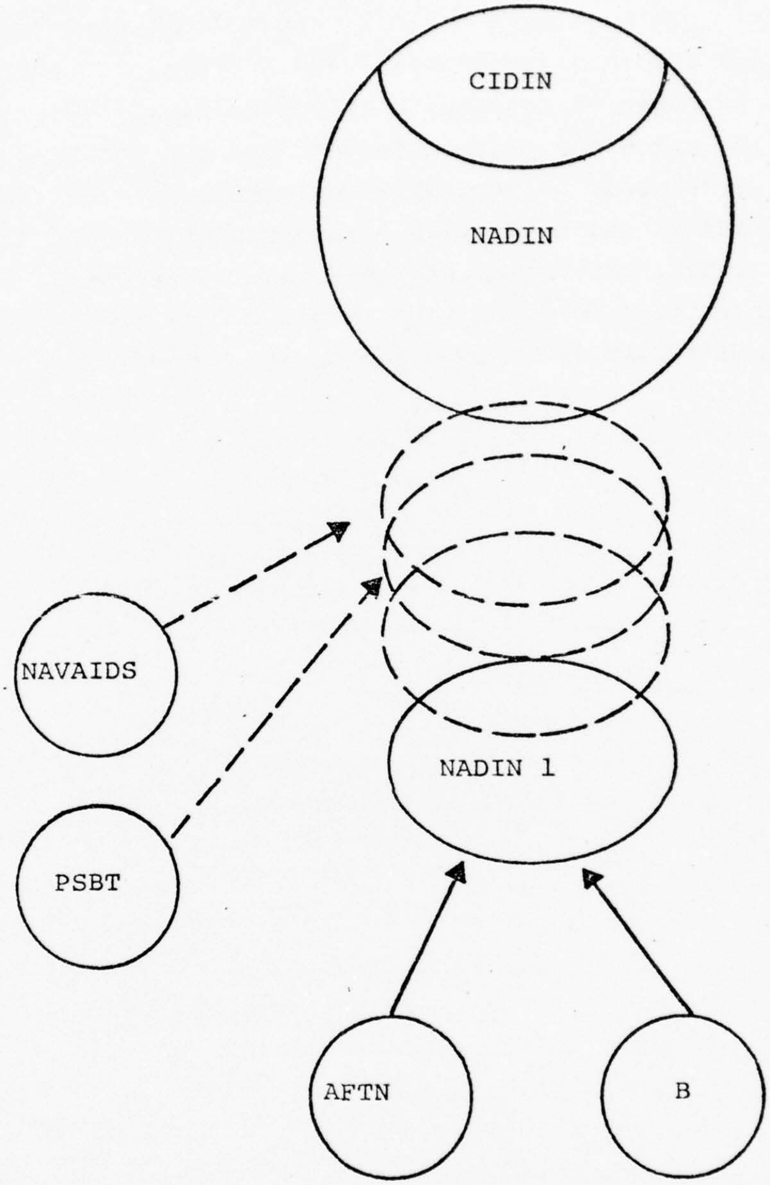

FIGURE 1-1: INTERRELATION OF SYSTEMS AND CONCEPTS

In Section 2 of this report, the operational requirements are briefly reviewed, and in Section 3 a brief discussion is given of the feasibility considerations. In Sections 4,5, and 6 the process of developing a NADIN architecture is presented; in Section 7 the conclusions of the study are presented; and in Section 8 recommendations and design considerations are presented. The basic sections of the report are written in brief form, and the detailed supporting analysis and discussion is found in the Appendices.

SECTION 2

OPERATIONAL REQUIREMENTS

2.1 PRESENT SITUATION

The design and engineering of a telecommunications network is dependent upon the form of the information to be carried, the desired distribution of the information, and the desired speed of information transfer. The AFTN and Service B network (except for the Computer B subnetwork not considered in this study) share many fundamental operational requirements. These common requirements are listed below:

a. The traffic is basically non-conversational i.e. immediate reply is not a requirement of the majority of messages.

b. The traffic has multi-addressed messages requiring simultaneous action.

c. A proportion of the messages is concerned with aircraft operations but not in the main with aircraft which are active in the ATC system or in flight. For this reason the end-to-end delivery times required are of the order of minutes rather than seconds.

d. The traffic content and precedence vary widely.

e. The traffic is offered on a random basis.

f. The traffic includes a proportion of messages in plain language in which errors are self-evident.

g. Almost all of the textual information conveyed is manually interpreted by the recipient; presentation is therefore geared to slow speed printers.

These requirements have been met by the AFTN and Service B networks which share the following network characteristics:

a. They are common user networks.

b. Access to the networks is random and traffic loads therefore vary widely with time.

c. They are message relay networks in which the addressing instructions are contained within the message.

d. The networks are composed primarily of low speed telegraph channels operating at 100 words per minute.

e. The code used in each network is the International Telegraph Alphabet No. 2 (Baudot).

f. There is no widespread employment of error detection and correction in either network.

The fundamental similarities of the networks as described above appear to make integration quite attractive. However, the networks also have significant differences. These are listed below:

a. The AFTN network handles messages primarily related to international flight activity, whereas the Service B network handles messages primarily related to domestic flight activity.

b. The AFTN network uses seven precedence levels, whereas the Service B network uses five precedence levels.

c. The message formats used in the two networks are different.

d. The geographical dispersion of AFTN terminals includes the Pacific, Alaska, and Caribbean regions, as well as the conterminous United States (CONUS), whereas Service B terminals are all located within the CONUS.

e. The message format and the device control procedures for the two networks are different.

f. Although both networks use Model 28 teletype terminals, the terminals are currently configured for different operating procedures and consequently AFTN terminals and Service B terminals cannot now be placed on a common circuit.

The operational requirements for an integrated network must include support of these differences until administrative decisions and equipment transitions lead smoothly to their resolution.

2.2 PROJECTED REQUIREMENTS

There is reason to believe that there exists considerable demand for additional access to a common user system within FAA. Flight Service Stations now accept over the phone many messages from various FAA administrative facilities. It is reasonable to assume that some administration facilities could effectively use direct access to a common user system. Generally we believe that because the present systems are overloaded demand has been inhibited and the availability of a new modernized system will reveal hitherto suppressed requirements. We discuss this further below.

Future demand for an existing service can be estimated fairly well based on operating experience. However, an improvement in service will usually generate new demand. For example, prior to the introduction of computer operated store-and-forward message switching, many manual tape relay

networks exhibited a stabilized growth curve. When computer message switches were introduced in these networks (usually for economic reasons), they were sized based on handling existing traffic with a modest growth capability determined by existing trends. However, in most of these systems, the traffic took a step-function increase considerably above existing levels. This happened because the improved speed of delivery offered by the network stimulated demand. This phenomenon has been readily observed following other well-known service improvements, e.g., overseas radio-telephone and cables, direct distance dialing, and communications satellites.

Demand for entirely new services is even more difficult to estimate because potential users are notoriously unreliable in predicting their own needs and usage for a new service, mostly, it seems, because they cannot visualize doing their business in a new way. Innovation in telecommunications has almost always come from the supplier and not the customer. It takes someone with knowledge of technological feasibilities to determine appropriate new services. This expertise has traditionally been found in the supplier who is also eager to market his service or equipment.

Because demand is difficult to predict, communication system planners have always found it necessary to design open-ended systems, that is to say, systems that are designed to allow expansion and growth.

In this study, use has been made of existing studies characterizing the present system and its growth requirements. This existing work is primarily contained in MITRE Corporation Reports MTR 4158 and MTR 1673. Appendix C presents the detailed traffic analysis that has led to the requirements used in this study.

We determined to our satisfaction that the <u>relative</u> growth predicted for traffic by station is a good basis for system planning. However, we offer an almost certain dictum for systems planning: absolute traffic projections will almost always be wrong. The reasons for this are many, but the most important is the phenomenon of new service awareness as discussed above.

The proper design strategy for large scale common user systems is to incorporate as a major design criterion the ability to expand network size economically.

Thus, we know from experience in planning many such networks that detailed knowledge of traffic flows at a message-by-message level is unnecessary. If such knowledge is necessary for a postulated design, then it is almost a certainty that the design is improper and the resulting network inadequate; it will never be able to survive the uncertainties of actual traffic flow in the real world of a dynamic network.

2.3 OPERATIONAL OBJECTIVES

It is clear that the FAA has a continuing requirement for a generalized common-user record communications facility whose basic operational requirements stem from current needs. A modernized system to meet those needs must have the capability to grow in an economical fashion and to utilize technological improvements that lower costs and improve service in an acceptable cost-beneficial manner.

The long term objective is a common user network in which operator procedures, message formats, and priorities are consistent within classes and in which terminals within classes are consistent in operation to the point of being able to share circuits. It is recognized that a single terminal class designed to meet the requirements of all users may not be cost effective. However, the introduction of different types of terminals that form inconsistent classes should occur

only after a deliberate decision based on consideration of the technical, operational, and economic factors involved. A variety of terminal classes must not occur by default. However, the short term objective must include support of the existing differences with continuous operational transitions. Thus, to develop a network architecture that satisfies the short term objectives and permits eventual satisfaction of the long term objectives, the following operational objectives are used as guidelines:

> Cost effective improvement of the existing services,
>
> Continuous operational transitions,
>
> Basic architectural consistency with the NADIN concept,
>
> Operational consistency with CIDIN guidelines where appropriate,
>
> Economic evolution from the existing system to the eventual system.

SECTION 3

FEASIBILITY APPRAISAL

3.1 TECHNICAL FEASIBILITY

Two major questions of technical feasibility were considered:

a. Is the technology available for a network architecture that will achieve cost-effective improvement of Service B and AFTN through the use of common facilities?

b. Is the technology available for a network architecture which will not only achieve cost-effective improvement of Service B and AFTN through the use of common facilities, but which will also allow smooth evolution into a common user network that will serve well as a kernel for NADIN development?

The first question deals with a limited scope objective of satisfying the immediate requirements of improving the existing services; the second question deals with a broad scope objective of not only satisfying the immediate requirements, but satisfying them in such a way as to permit satisfying the long term objectives. The answer to both questions is affirmative.

The rapid advances in the technology of multiplexers, concentrators, and message switching computers have brought an available level of technology that clearly indicates technical feasibility of cost effective architectures for message switching networks satisfying the general FAA requirements. Several networks satisfying similar requirements for other organizations are currently in existence. The operational transparency of multiplexers guarantees, at least, the

feasibility of reducing current operating costs by sharing leased lines. The software flexibility of concentrators and message switching computers makes it feasible for the existing services, with their incompatible differences, to share these facilities permitting possibly greater cost reductions. It is, in fact, the flexibility and efficiency of the software approach to concentrators and message switching computers that permits an affirmative answer to the second question.

In a previous study, reported in DOT/FAWA2707, Network Analysis Corporation and Telcom presented a network architecture for modernizing Service B that satisfied the basic objectives of cost effective improvement in service, and flexibility in vertical growth to satisfy growing service demands and horizontal growth to satisfy a broadening scope of services. The architecture used mini computer concentrators and switches to establish a backbone network for data communications. The capability of this architecture to satisfy the combined requirements of AFTN and Service B depends on the level of throughput it can support and the potential of the concentrators servicing the operationally incompatible terminal sets. The referenced study indicated more than enough potential throughput capacity, while the software flexibility of the concentrators ensured feasibility of serving the distinct terminal sets. Thus, this architecture represents one feasible alternative for satisfying the broad objectives raised in the second question of feasibility.

With the feasibility of satisfying the overall objectives for integrating AFTN and Service B with available technology identified as affirmative, it remains to develop the most approporate architecture for the integrated network. The remaining sections of this report present this development.

3.2 ADMINISTRATIVE FEASIBILITY

The network architecture presented in this report for the integration of AFTN and Service B has the potential for evolving to satisfy the long range objectives identified in the NADIN concept. Implementation of the network will satisfy the short term objectives. However, satisfaction of the long term objectives will require an affirmative action program on the part of FAA administration to evolve operational consistency and integrated planning, operation, and control.

SECTION 4

ARCHITECTURE ALTERNATIVES AND EVALUATION CRITERIA

4.1 EVALUATION CRITERIA

There are several network architectures that may be considered for NADIN I. The selection of an appropriate architecture must be based on evaluation of the alternatives according to many criteria, including:

Performance,

Cost,

Reliability,

Growth,

Consistency with objectives for NADIN.

These criteria are used in the evaluations made in this report as they are the ones that can be appraised on a technical basis. The criteria are briefly discussed below. However, it should be noted that FAA must make its own evaluation based not only on the above criteria, but on other criteria outside the scope of a technical appraisal. These include location problems, personnel difficulties, administrative requirements, etc.

4.1.1 Performance

For a network such as envisioned here, "performance" is usually defined in terms of the time it takes a message to traverse the network from entry to exit (which will be called traversal time) and the traffic level the network experiences (which is called the throughput). These two attributes of a network are interrelated, and performance

is usually characterized by the average traversal time as a function of the throughput.

In general, network design is oriented towards achieving an "acceptable performance" specified as an average traversal time for a given throughput. However, in NADIN, many of the physical aspects of the network affecting the performance are fixed (i.e., Model 28 teletypes). Without knowing the impact of this limitation it is very difficult and even dangerous to specify a priori a required performance for the network design. An appropriate alternative is to investigate the factors that will contribute to the traversal time in terms of the given equipment constraints and, on the basis of this investigation, develop design constraints and requirements that are consistent with the overall network objectives and good engineering. It is this course which has been taken here. Following this approach, the designs considered have been evaluated on the basis of their basic throughput capacity, while not exceeding traversal delays achievable by good engineering, but subject to existing equipment constraints. In all cases considered, the alternative designs were calculated to have acceptable delays in terms of the operational requirements outlined previously.

4.1.2 Cost

The cost of the network designs may be viewed as composed of three basic components:

Leased lines cost,

Transmission equipment cost,

Intelligence cost.

The leased lines cost is simply the monthly charge for use of the teletype and voice grade lines employed in a design. The

transmission equipment cost includes the multiplexers and modems required to realize the designs. The intelligence cost includes the cost of concentrators and message switching computers. The concentrators are included in this component rather than as part of the transmission equipment because of the direct impact they have on the characteristics of the central switch required. The intelligence cost includes both hardware and software cost based on turnkey implementation.

In all cases, the resultant cost for a design is expressed as a monthly charge based on a 10-year amortization schedule at 10%. This permits an easy comparison of the alternatives.

4.1.3 Reliability

The reliability of a data communications network such as NADIN I may be characterized in a great many ways. It is dependent on two fundamentally distinct factors: the hardware component reliability and the structural properties of the network. The vendors of hardware have historically been conscious of the reliability aspects of their products (although not always concerned). Unfortunately, many networks are being designed today with little consciousness on the part of the designer of the reliability impact of the network structure. The three measures of reliability used in this study reflect both the reliability aspects of the network structure and the reliability impact of equipment failures. The three measures of reliability are:

- FNP - The fraction of node pairs that can communicate,
- FNC - The fraction of nodes that can communicate with a central switch,
- WTD - The worst-case probability that a terminal will be disconnected from a switch.

The FNP measures the general reliability of the network, whereas the WTD measures the worst-case reliability that may result from the design. The FNC measures the reliability in terms of the users' capability to communicate with an intelligent center, at which network status messages and other general administrative messages are generated and received. These three measures were chosen over other reliability measures as these three are most indicative of the disruption of service brought about by random failures of components within the system.

4.1.4 Growth

The term, growth, is interpreted as having both a vertical and a horizontal component in the network. Vertical growth is the ability to handle more terminals and heavier traffic. Horizontal growth is the ability to handle a broader variety of service requirements. The vertical growth potential is easily measured as the basic throughput capacity of the system, subject to delay constraints. The horizontal growth potential is not easily measured and consequently is appraised in more qualitative terms.

4.1.5 Consistency With Objectives For NADIN

The network designs are also appraised in terms of their consistency with the basic objectives of the NADIN concept. In particular, they are appraised in terms of their potential for serving as a kernel for development into a basic integrated common user network in a cost-effective manner.

4.2 CONCLUSIONS OF PREVIOUS STUDY AND THEIR VALIDITY

A previous study referred to above was conducted by Telcom and Network Analysis Corporation to "synthesize requirements, technology, and analysis to recommend the most viable technical development strategy for modernizing Service B" (DOT/FAWA2707). Several conclusions were drawn in the study

which bear directly on the subject of this study. In this section, these conclusions are reviewed and their validity with respect to an integrated AFTN and Service B network are examined.

4.2.1 Number of Switching Centers

The previous study examined several different architectures for a modernized Service B network, evaluating each in terms of the basic criteria presented above. The number of switching centers considered for the new network was varied from one to ten. It was found that neither line cost nor reliability was significantly affected by the number of centers, except that more than one center was necessary to ensure reliability in the event of catastrophic disasters eliminating a center. Thus, because of the expense of centers, the recommended architecture was based on two geographically dispersed centers.

For the early phases of the portion of NADIN located in the CONUS, this conclusion appears quite valid also. The number of AFTN terminals in this region is small in comparison to the number of Service B terminals and does not appear to impact the basic conclusion. Thus only architectures of two geographically dispersed switching centers for the CONUS portion of NADIN are considered in this study.

4.2.2 Line Mix

The previous study examined three possible line configurations: all teletype, all voice grade, and a mixture based on traffic. The last was found favorable in all respects. The validity of this conclusion for NADIN appears clear and is the only alternative considered in the design study.

4.2.3 Multiplexers and Concentrators

The previous study examined the trade-off between multiplexers and concentrators and concluded that designs with either were uniformly better than designs with neither.

Concentrators gave designs of basically the same cost as multiplexers, but achieved considerably better growth potential with much less sensitivity to possible chance in traffic characteristics. This conclusion has been reviewed in this study and found to be quite valid for NADIN. It is reinforced by the objective of NADIN to establish a kernel for further development as a common user network. The utilization of concentrators provides a cost-effective means of evolving an increasing capacity and broadening of scope. The use of multiplexers is much less flexible.

4.2.4 Reliability

A basic insight provided in the previous study was that concentration devices tend to improve network reliability characteristics by reducing the average number of links messages must traverse to reach a switching center, even when the concentration devices themselves are less reliable than the links. This conclusion reinforces the basic conclusion favoring designs with concentration devices over designs without concentration devices.

4.3 ARCHITECTURE VARIABLES

The results of the previous study give considerable justification for an architectural strategy of two major switching centers in the CONUS and the use of concentrators. However, it left for subsequent development a network design for the extended system which verifies these conclusions and which also appropriately answers several additional questions, including:

Where should the switching centers be located?

Where should the concentrators be located?

Should there be switching centers, concentrators, or multiplexers in the Alaska and Hawaii regions?

What is the cost of a network resulting from the integration of Service B and AFTN?

The answers to these questions as well as an appropriate design for NADIN are developed in the next two sections.

SECTION 5

DESIGN CONSIDERATIONS

5.1 SYSTEM CONSTRAINTS

The initial phase of the NADIN is to be a common user network serving the FAA data communication requirements currently being served by the Service B and AFTN networks. Because these existing networks are well established, operational, highly utilized, and represent a significant investment in dollars and human resources for operation, their upgrading and integration as the initial phase of NADIN must be done as efficiently as possible. This not only must encompass a smooth evolution of operational procedures and hardware transitions, but must also be done in a manner consistent with the basic objectives for NADIN. This implies a guiding principle of using existing facilities and operating procedures where such usage does not impair achievement of the communication requirements. In this study, several constraints for NADIN designs have been developed on the basis of the above guiding principle and the following observations:

> The equipment characteristics and operating procedures for terminals in the existing networks are not uniform, prohibiting indiscriminate placement of terminals on multidrop circuits.
>
> New terminals operationally consistent with ANSI standards and with each other will replace the older terminals as either traffic or operational considerations require.

The constraints have been determined by dividing the terminals into categories, such that all terminals in any particular category will be compatible to the point of being able to be placed on a common multidrop circuit, but terminals in different categories cannot share a circuit. The basis for division includes physical characteristics of the terminals, compatibility of operating procedures, and administrative policies.

NADIN is to provide an integrated telecommunications service to locations distributed in four major regions:

CONUS

Alaska

Pacific

Caribbean

In order to use existing equipment within each region, twelve categories of terminals have been defined that permit design based on existing facilities and operational restrictions. The development of these categories is detailed in Appendix A. For locations requiring terminals other than those currently available, a medium speed, ANSI-consistent terminal is assumed. The twelve basic categories are summarized below:

CONUS

1. All Area B, Supplemental B, and Center B locations.

2. All Military Air Base Operations Offices (BASOPs) currently served by Service B circuits.

3. All airline locations currently served by Service B circuits.

4. All AFTN terminals.

ALASKA

5. Alaska outlying locations.

6. Anchorage non-airline locations.

7. Anchorage airline locations.

PACIFIC

8. Hawaiian Island non-airline locations.

9. Honolulu airline locations.

10. Pacific outlying locations.

CARIBBEAN

11. Caribbean non-airline locations.

12. Caribbean airline locations.

A listing of all locations in each category is contained in Appendix H.

5.2 TOPOLOGICAL CONSTRAINTS

As part of the NADIN design process various topologies of circuits interconnecting terminals, concentration facilities (CFs), and switching centers (SCs) are evolved. There are many constraints on the topologies resulting from traffic, performance, and reliability considerations. However, there are also many practical considerations on the feasibility of obtaining circuits that also lead to constraints on the topologies. Furthermore, there are practical considerations which also simplify the topological design process. In this section, these various practical considerations and their impact on the NADIN topology design process are discussed.

5.2.1 Local Constraints

There are several situations in which terminals in the immediate proximity of one another are connected. These situations are easily divided into two categories: airline facilities at airports and terminals collocated with a Concentration Facility (CF). The circuit layout for such terminals is primarily dictated by local cost considerations and the cost of connecting circuits to a CF.

5.2.2 Intraregion Constraints

In order to determine topological constraints based on practical considerations of obtaining circuits, it is appropriate to examine each of the four NADIN regions individually. Within each of these regions, there are practical considerations affecting the availability of circuits. These considerations are discussed in detail in Appendix B. One optional constraint is of particular interest, the possibility of developing circuits on an ARTCC-region basis. This constraint reflects administrative considerations of the FAA. The following statement is a formal specification of the constraints for this option, which will be called the ARTCC constraint option.

ARTCC Constraint Option

1. Every ARTCC is to have a CF of some form.
2. All terminals in the region of responsibility of an ARTCC are to be connected to the CF at the ARTCC.

This option will differ from the unconstrained case in both cost and traffic characteristics for the high level side of the network. These differences are appraised in Section 6. The locations subject to this constraint are listed in Appendix H on a regional basis.

5.2.3 Interregion Constraints

The four regions of NADIN are geographically disjoint. The options available for the interconnection of these regions are determined by the presence of existing communication facilities. The options are described below.

Pacific-Alaska

Cable between Honolulu and Anchorage

Satellite between Honolulu and Anchorage

Pacific-CONUS

Cable between Honolulu and San Francisco

Cable between Honolulu and Los Angeles

Satellite between Honolulu and San Francisco

Alaska-CONUS

LOS microwave combined with cable from Anchorage to Seattle

Satellite between Anchorage and Seattle

LOS microwave between Anchorage and Montana

CONUS-Caribbean

Cable between Miami and San Juan

Cable and microwave facilities are to be preferred over satellites where economics permit due to the propagation delay (about 250 ms originator to destination) in satellite systems.

5.3 TRAFFIC CONSIDERATIONS

In order to design a cost effective network with satisfactory performance, appropriate traffic information describing the expected load for the network is required. However, it should be emphasized that proper network design does

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not result from tailoring the design to detailed knowledge of traffic flows at a message-by-message level. Any network designed on such a basis will never be able to survive the uncertainties of actual traffic flow in the real world of a dynamic network. Thus, in the NADIN design process, the traffic projections on a per station basis were used and the resulting designs were carefully appraised for sensitivity to traffic variations and growth.

An appropriate traffic portrait for use in designing networks such as NADIN includes considerations of message length distribution, distribution of message arrivals at terminals, the rates at which messages arrive at the terminals, and the source-destination characteristics of the messages. It is often both impossible and inappropriate to determine and use these traffic characteristics in detail. As noted above, the network design should be tolerant with respect to changes in these characteristics, which will occur as the system evolves. However, it is necessary to formulate a reasonable, conservative portrait of the traffic characteristics in order to determine the necessary capacity of network components. In Appendix C, such a portrait is fabricated. Its major characteristics are discussed below.

5.3.1 Message Length Distribution

Terminals in the NADIN are expected to handle several different categories of messages, including all those currently handled by Service B and AFTN terminals, and possibly some new categories.

The message length distributions for the two different existing systems are different, due to differences in both format and content. However, current administrative policies are directed at making the basic message formats consistent. Furthermore, although initially the existing terminals

will serve primarily in their present roles, the evolving integration of the network will lead to terminals serving more general functions. With these considerations in mind and with an objective of developing a general and conservative portrait, it appears that a common message length distribution for all terminals is appropriate. To develop this distribution, consideration was first given to the existing networks, then to the integrated network.

The resulting distribution is a biased exponential having an average message length of 110 characters, with a constant component of 40 characters.

5.3.2 Message Arrival Distribution

The arrival pattern of messages to either AFTN or Service B terminals is almost impossible to determine from the measured traffic statistics. However, in most communication systems messages arrive randomly and independently. These are the basic attributes of a Poisson process. The message arrival distribution is primarily of interest in the performance analysis of the multidrop lines. These lines are shown to be appropriately modeled as single server queues, with the arrival pattern to each queue being the sum of the arrivals at the individual terminals on the line. It has been shown in many analyses for such queues that, if there are several inputs to the server, the arrival distribution to the server can be approximated as a Poisson distribution regardless of the distribution types of the individual inputs. Thus, with this consideration and the preceding one, the arrival pattern of messages to the terminals in NADIN was modeled as Poisson.

5.3.3 Message Arrival Rates

A primary requirement for the NADIN network is acceptable response time under the traffic loads anticipated for the next ten years. To appraise the performance of network

designs in meeting this requirement, it is first necessary to define and quantify the "acceptable response time" and "anticipated traffic loads".

With a given message length distribution and arrival pattern, the load may be defined as the average arrival rate of messages from outside the network to the entry points of the network.

The NADIN, like most networks, will experience periods of peak activity. The acceptability of a network design will be based in part on its performance during this peak period. In NADIN, this period is appropriately selected as an hour and the traffic load will then be expressed in terms of the "busy hour". The data describing traffic levels in the existing networks is usually expressed in characters per hour. Knowing the message length distribution, this can easily be related to messages per hour when necessary for analysis. Thus, the traffic loads developed in this study are in terms of characters per busy hour. To develop the load projections, data available for the existing systems has been extensively used. The development of the load projections is detailed in Appendix C, and individual terminal projections are given in the list in Appendix H.

5.3.4 Message Routing

Messages originating at a terminal may be destined to:

1. A terminal on the same circuit,
2. A terminal on a different circuit served by the same CF,
3. The NAS 9020 computer at the CF,
4. A terminal served by a different CF.

The division of the traffic over these four categories affects the appropriate sizing of the channels between CF's and SC's and between SC's, and the constraints for the number of terminals on a circuit. However, accurate information on the routing of the traffic is very hard to obtain, as noted in MITRE Report MTR-1673, and furthermore, should be considered as subject to change. Thus, for appropriate sizing of the channels and development of circuit constraints, conservative assumptions have been made coupled with sensitivity analysis. These assumptions and the related analysis are the subject of Appendix D.

5.4 PERFORMANCE-RELATED CONSTRAINTS

In order to develop appropriate performance criteria and constraints for the design process, considerable analysis has been developed in Appendix D. The analysis is based upon first identifying the limitations on performance imposed by existing equipment usage and then the development of consistent design constraints reflecting good engineering. These constraints are listed below.

For polled Service B circuits with existing equipment,

$$\lambda \leq 19.0 - .6M \text{ KCHR/HR}$$

For polled AFTN circuits using existing equipment,

$$\lambda \leq 20.0 - .2M \text{ KCHR/HR}$$

For polled circuits using new 1200 bps ANSI-consistent terminals,

$$\lambda \leq 210 - 6M \text{ KCHR/HR}$$

where λ is the traffic level on the circuit during the peak hour and M is the number of terminals on the circuit.

Use of ICAO-recommended procedures for data interchange has been assumed for circuits between concentrators and switches and use of the full CIDIN procedures has been assumed between switches. The performance implications of these assumptions have been analyzed in Appendix D, and are found quite satisfactory.

5.5 RELIABILITY CONSIDERATIONS

Several aspects of reliability have already been discussed. A detailed discussion and analysis is presented in Appendix E. The conclusions drawn from the analysis are:

The use of concentrators in the network design improves reliability significantly.

Concentrators which perform local switching improve reliability insignificantly as compared to concentrators which do not perform switching.

A line constraint of five terminals per line ensures reliable service to all users with insignificant cost impact when concentrators are used.

Reliability can be significantly improved with little increase in cost by using a multiplexing dial-up redundancy scheme.

5.6 COST CONSIDERATIONS

The equipment costs used in this study are detailed in Appendix F, and are summarized here in Table 5-1.

The line tariffs used in the designs are based on derived Telpak circuits, where the basic Telpak rate was increased by 20% to reflect the fact that direct routing is not always available and to account for IXC charges.

TYPE	PURCHASE ($)	AMORTIZED COST (+1% maintenance) ($/month).
	MODEMS	
< 1200 bps	$ 500	$ 13.33
1800	750	20.00
2400	1,780	47.45
3600	3,620	96.51
4800	4,800	127.97
7200	7,200	191.95
9600	9,750	259.94
	MULTIPLEXERS	
FDM	$ 400/channel	$ 10.67/channel
TDM	2,500/station + 150/channel	67.00/station + 4.00/channel
	CONCENTRATORS	
	$24,000 + $350/low speed line	$ 640.00 + $9.33/ low speed line
	SWITCHES	
CATEGORY 1 for network without concentrators	$700,000	$ 18,662
CATEGORY 2 for network with concentrators	400,000	10,664
CATEGORY 3 for small subnet (Alaska or Honolulu)	360,000	9,598

TABLE 5-1: SUMMARY OF EQUIPMENT COST

Line Cost

Teletype	$.25/mile
Voice Grade	$.50/mile

Terminal Connect Cost

$ 40/terminal

A basic tariff acquired from RCA Globecom Alaska for Alaska circuits is given below:

. 45 bps half-duplex 8 A.M. - 5 P.M. $.10/hour/mile/month
5 P.M. - 8 A.M. $.04/hour/mile/month

25% additional for 75 bps half-duplex service

25% additional (over the 75 bps half-duplex) for 75 bps full-duplex service

. 2000 type channel - half duplex

0 - 250 miles	$3.50/mile/month
250 - 500 miles	$3.15/mile/month
500 - miles	$2.80/mile/month

25% additional for a 3000 type half-duplex channel

25% additional (over the 3000 type half-duplex) for 3000 type full-duplex service

This tariff yields the following cost structure for full-duplex full-period leased circuits:

Alaska Line Cost

75 bps	$2.35/mile
1200 bps	
0 - 250 miles	$5.47/mile
250 - 500 miles	$4.92/mile
500 -	$4.38/mile

In addition, connection of Anchorage to CONUS has been priced by RCA Globecom Alaska as follows:

Anchorage - Seattle Line Cost

Voice Grade	$3,100/month

Anchorage - Montana

Voice Grade	$3,594/month
TTY	$2,542/month

The cost of a sub-voice grade line connecting Hawaii to the mainland is $2,904/month, and the cost of a voice-grade line is $6,600/month.

The costs described in the preceding paragraphs were used in the network cost calculations in making the evaluations of network architecture described in Section 6 following.

SECTION 6

EVALUATION OF NETWORK ARCHITECTURES

6.1 INTRODUCTION

The purpose of this section is to outline the process which has led to a recommended architecture for NADIN and to present the recommended architecture. The process of network design, although immensely aided by computer analysis, is still a human task. The analyst must develop reasonable constraints for the network designs and conceive fundamentally sound strategies for a network architecture. The previous sections have discussed the design constraints and architectural strategy. This section outlines the steps taken in developing the strategy into a network design consistent with the constraints.

The AFTN and Service B networks are located in the four geographic regions previously mentioned: the CONUS, Caribbean, Alaska, and Pacific regions.

The network topology appropriate for each region is independent of the other regions. However, the network architectures on which the topologies are based may be affected by the architecture within each region. Thus, the fact that message switching capability in CONUS will be accessible from other regions makes provision of local switching capability in the other regions a question of benefit rather than a matter of necessity.

The Alaska, Pacific, and Caribbean regions have clear geographical justification for centralized topologies, with centers at Anchorage, Honolulu, and San Juan, respectively. Four basic architectural alternatives are then available:

a. Placing a multiplexer at the central location and doing all switching elsewhere,

b. Placing a concentrator at the central location and doing all switching elsewhere,

c. Placing a concentrator at the central location and doing all switching requiring journaling elsewhere, but other switching locally, or

d. Placing a switch at the central location

The situation for the CONUS is considerably more complex. Even with a basic architecture established of two switching centers and the use of concentrators at ARTCC's substantial questions of topology remain. In the next section, these questions are resolved and the following section considers the alternatives for the other regions. The last section gives the combined resultant network design.

6.2 CONUS

The evaluation of the architectural variations to be considered for CONUS is almost entirely dependent on Area B considerations. This is because of the relatively large number of Area B terminals, their geographic dispersion, and the little impact on the topology of the other components of the Service B and AFTN networks that result from the variations considered. Consequently, in the discussion which follows, consideration will be restricted to Area B.

6.2.1 Baseline System

The baseline design considered for CONUS is composed of two switching centers geographically separated, but in the immediate vicinity of Kansas City, and 20 concentrators, one at each ARTCC, connected in a point-to-point manner with the switching centers. For purposes of topological analysis, the two centers are considered as one located at Kansas City. The basic design for 1975 traffic is shown in Figure 6-1* and its structure and cost are detailed in Table 6-1. Kansas City was selected for the centers because of its proximity to the geographic center of the country. For comparison purposes, a

*Figures 6-1 through 6-9 and Figures 6-11 through 6-12 are maps which may be found at the end of this Section

design composed of Kansas City located switches but no concentrators is shown in Figure 6-2; its structure and cost are detailed in Table 6-2. Both designs were subject to the same reliability and performance constraints. A comparison of the two designs indicates that even at 1975 traffic loads with a concentrator at every ARTCC, the use of concentrators is still cost effective. A study is currently in progress to determine the most efficient manner to evolve NADIN implementation, which may result in procedures to use fewer concentrators in the initial stages. However, in this study, concentrators are assumed present at all ARTCC's, reflecting the general strategy for NADIN and giving worst case cost results for evaluation purposes.

6.2.2 ARTCC Constraint

For administrative purposes, it appears attractive for Area B circuits to be entirely contained within the regional domains of the ARTCC's at which they are terminated. This constraint somewhat restricts the topological variations that can be achieved in the design process. However, no significant cost effects result. A design with the area constraint is shown in Figure 6-3 and, as can be seen from its corresponding description table (Table 6-3), there is only about 1% increase in network cost in comparison to the baseline design. It is assumed that this minor increase in cost is warranted by personnel considerations.

6.2.3 Multipoint Concentrators

It is apparent from examination of the baseline design that further savings could be achieved by staging the concentrators. In Figure 6-4 such a design is shown. As detailed in Table 6-4, the resulting cost of the design is somewhat less than that of the baseline design. The reduction in cost is about 3.5%, sufficient to be worthwhile, yet insufficient to

be of concern if traffic increases or new requirements cannot be met without a point-to-point configuration. Within the 1984 timeframe, the projected requirements can all be satisfied with such a staged configuration. Because of the multiplexing redundancy and dial-up backup provided for all concentrators, the reliability of the two designs is virtually equal. The staging of the concentrators will introduce a new delay component, but because of the line speeds specified for the concentrator interconnect circuits, the additional delay will be negligible.

6.2.4 Switching Center Locations

In addition to the baseline switching center location of Kansas City, two other alternatives were examined: Kansas City and Washington, and Denver and Indianapolis. The Kansas City and Washington locations reflect administrative considerations for collocating the switches at major FAA facilities involved with related network activity. The Denver and Indianapolis locations are selected for a least-cost comparison. The resulting designs are shown in Figures 6-5 and 6-6, and are detailed in Tables 6-5 and 6-6. As can be seen from the tables, the cost differences are insignificant, differing only by about .5%. Thus, all of the three options are considered equally attractive.

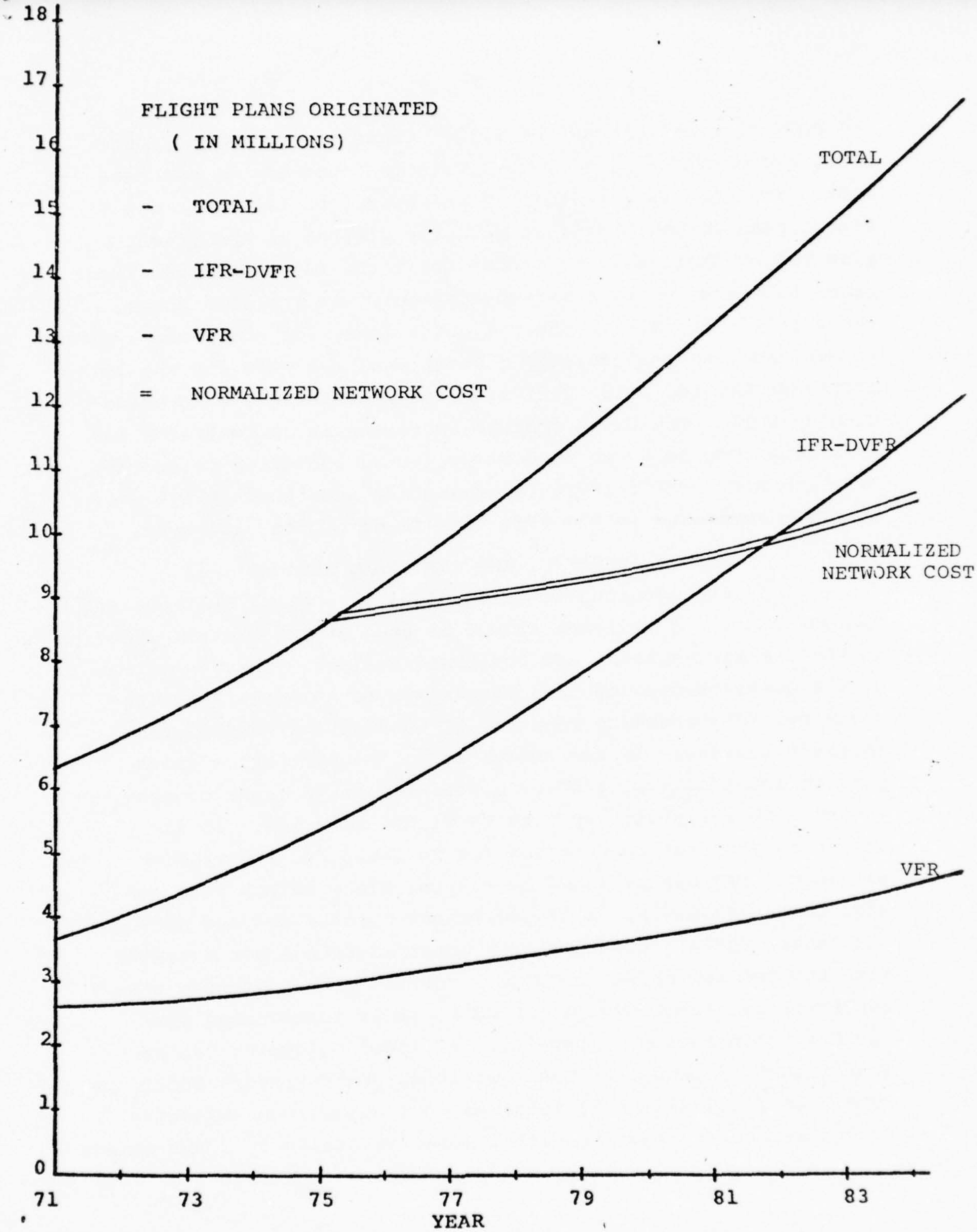
6.2.5 Growth Cost Analysis

In order to evaluate the network architecture evolved above in terms of growth, designs based on the architecture were developed to satisfy 1977, 1980, and 1984 traffic requirements consistent with the performance and reliability constraints developed earlier. These designs are shown in Figures 6-7, 6-8, and 6-9. The traffic levels on which the preceding design considerations are based follow the flight plan volumes predicted in

the DOT aviation forecast of 1973. These are shown in Figure 6-10, along with a plot of the projected cost of the new network. The cost is normalized with respect to 1975 cost and flight plan volume. What is actually plotted is the flight plan volume that would be processed if the 1975 ratio of flight plans to system costs remained constant. As the plot shows, the rate of increase in the projected load, for which the system is designed, is considerably greater than the rate for the 1975 unit-cost-related load, indicating an increasingly cost-effective network. The costs include increases in concentrator and switching computer core to meet projected increases in storage requirements. The incremental costs are amortized at 10% over the time remaining in the 1984 time frame of the equipment.

6.3 ALASKA, PACIFIC, AND CARIBBEAN REGIONS

The question to be resolved is whether multiplexers, concentrators, or switches should be used at the central locations in the Pacific, Alaska, and Caribbean regions. The resolution of the question depends upon the answer to an administrative question: is journaling required of locally switched messages in these regions? If the answer is no, concentrators which perform local switching offer a cost-effective means of providing high reliabilility service within a region. If the answer is yes, the requirement for reliable local operation within the regions provided by a local minor switch with its high costs ($350,000, or $9,600/month) must be weighed against the lesser costs and reliability obtained from a concentrator with remoted switching in CONUS. For the same reasons a concentrator is recommended at ARTCC's, it is recommended for the Caribbean region. Therefore, if local switching can be done without journaling, then switching concentrators should be used. If local switching requires journaling, non-switching concentrators are favored with remoted switching in CONUS unless



FLIGHT PLANS ORIGINATED
(IN MILLIONS)
- TOTAL
- IFR-DVFR
- VFR
= NORMALIZED NETWORK COST
TOTAL
IFR-DVFR
NORMALIZED NETWORK COST
VFR
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
71
73
75
77
79
81
83
YEAR

FIGURE: 6-10

local reliability is deemed worth the expense by FAA administration. Thus in Alaska, Hawaii and the Caribbean, concentrators are favored.

Each region should be connected to CONUS via a voice grade facility to ensure acceptable response times for messages traversing between centers and reasonable insensitivity to traffic growth. A sub-voice grade channel would introduce an additional low speed channel and queueing delay that would impair network performance objectives. The use of a multiplexer would avoid the additional delay because of its functional extension of the terminal circuit directly to the switch.

6.4 NADIN ARCHITECTURE

The network designs considered in this study have all satisfied the performance and reliability constraints presented earlier and thus are assumed of equal evaluation in terms of these measures. For the measures of cost, growth, and consistency with the NADIN concept, the uniformly best architecture is composed of two major switching centers in CONUS, with concentrators at ARTCC's, Anchorage, Honolulu, and San Juan. The NADIN network design for 1975 traffic is shown in Figure 6-11, and for 1984 traffic in Figure 6-12.

Center:	Kansas City
Concentrators:	21 Point-to-point
Traffic:	1975
Service:	Area B
Area Constraint:	No

Leased Lines Cost:	$33,457
Trans. Equip. Cost:	533
Intelligence Cost:	
Switches	21,328
Concentrators	15,515
	$70,833

TABLE 6-1 BASELINE DESIGN
(FIGURE 6-1)

Center:	Kansas City
Concentrators:	None
Traffic:	1975
Service:	Area B
Area Constraint:	No

Leased Lines Cost:	$37,928
Trans. Equip. Cost	-
Intelligence Cost	37,324
	$75,252

TABLE 6-2 COMPARISON SYSTEM
(FIGURE 6-2)

Center:	Kansas City
Concentrators:	21 Point-to-point
Traffic:	1975
Service:	Area B
Area Constraint:	Yes

Leased Lines Cost	$34,158
Trans. Equip. Cost	533
Intelligence Cost	
Switches	21,328
Concentrators	15,593
	$71,612

TABLE 6-3 VARIATION A

(FIGURE 6-3)

Center:	Kansas City
Concentrators:	21 Multipoint
Traffic:	1975
Service:	Area B
Area Constraint:	Yes

Leased Lines Cost	$29,638
Trans. Equip. Cost	1,977
Intelligence Cost	
Switches	21,328
Concentrators	15,515
	$68,458

TABLE 6-4 VARIATION B
(FIGURE 6-4)

Centers:	Kansas City, Washington
Concentrators:	21 Multipoint
Traffic:	1975
Service:	Area B
Area Constraint:	Yes

Leased Lines Cost	$29,620
Trans. Equip. Cost	2,156
Intelligence Cost	
Switches	21,328
Concentrators	15,515
	$68,619

TABLE 6-5 VARIATION C

(FIGURE 6-5)

Centers:	Denver, Indianapolis
Concentrators:	21 Multipoint
Traffic:	1975
Service:	Area B
Area Constraint:	Yes

Leased Lines Cost	$29,411
Trans. Equip. Cost	1,977
Intelligence Cost	
Switches	21,328
Concentrators	15,515
	$68,231

TABLE 6-6 VARIATION D

(FIGURE 6-6)

Centers:	Denver, Indianapolis
Concentrators:	21 Multipoint
Traffic:	1977
Service:	Area B
Area Constraint:	Yes

Leased Lines Cost	$29,719
Trans. Equip. Cost	1,977
Intelligence Cost	
Switches	21,328
Concentrators	15,541
	$68,565

TABLE 6-7 VARIATION D1

(FIGURE 6-7)

Centers:	Denver, Indianapolis
Concentrators:	21 Multipoint
Traffic:	1980
Service:	Area B
Area Constraint:	Yes

Leased Lines Cost	$30,201
Trans. Equip. Cost	2,250
Intelligence Cost	
Switches	22,928
Concentrators	18,396
	$73,775

TABLE 6-8 VARIATION D2
(FIGURE 6-8)

Centers:	Denver, Indianapolis
Concentrators:	21 Multipoint
Traffic:	1984
Service:	Area B
Area Constraint:	

Leased Lines Cost	$33,704
Trans. Equip. Cost	5,118
Intelligence Cost	
Switches	26,128
Concentrators	22,076
	$87,026

TABLE 6-9 VARIATION D3

(FIGURE 6-9)

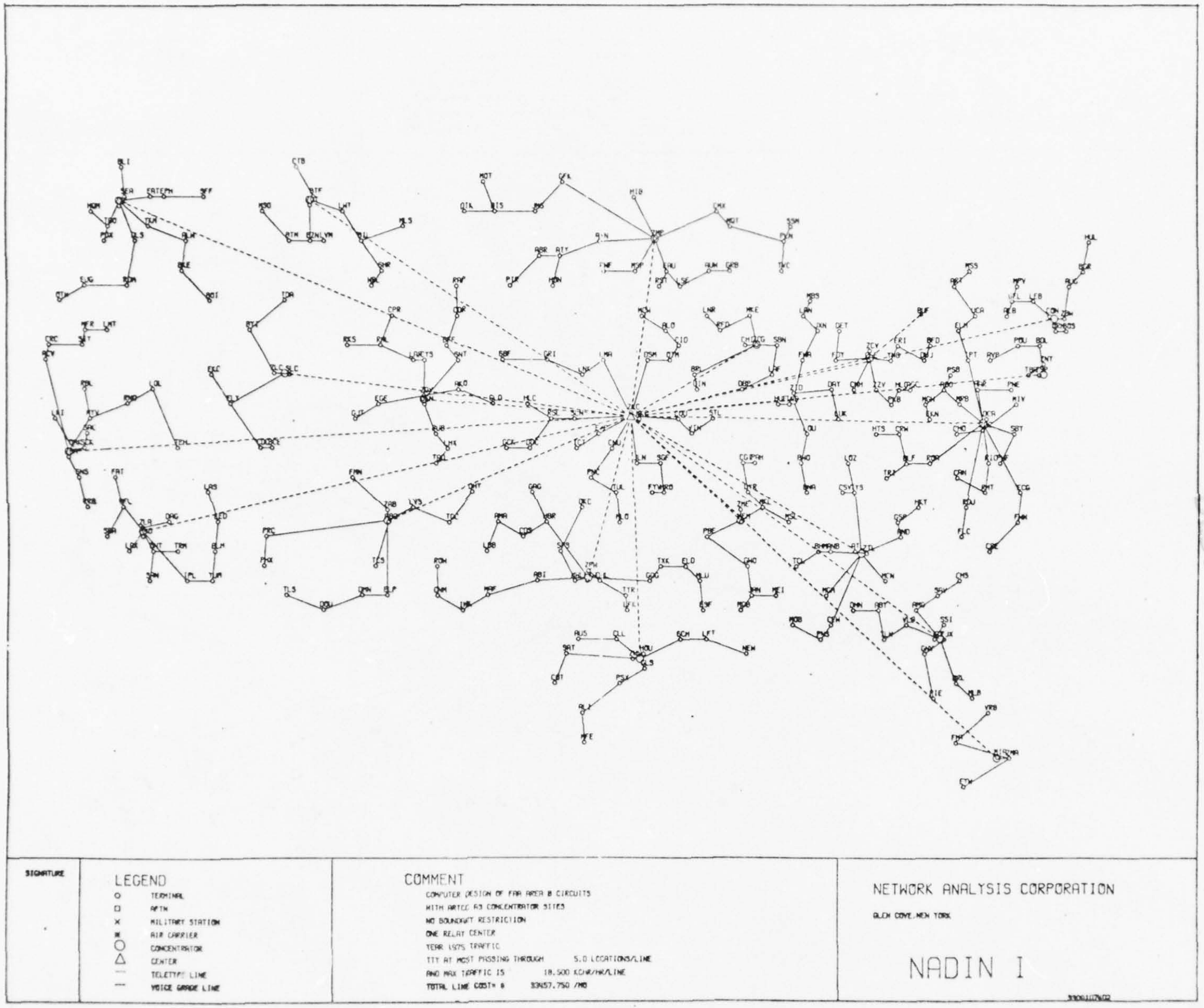

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC A3 CONCENTRATOR SITES
NO BOUNDARY RESTRICTION
ONE RELAY CENTER
YEAR 1975 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18.500 KCHR/HR/LINE
TOTAL LINE COST= $ 33457.750 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-1

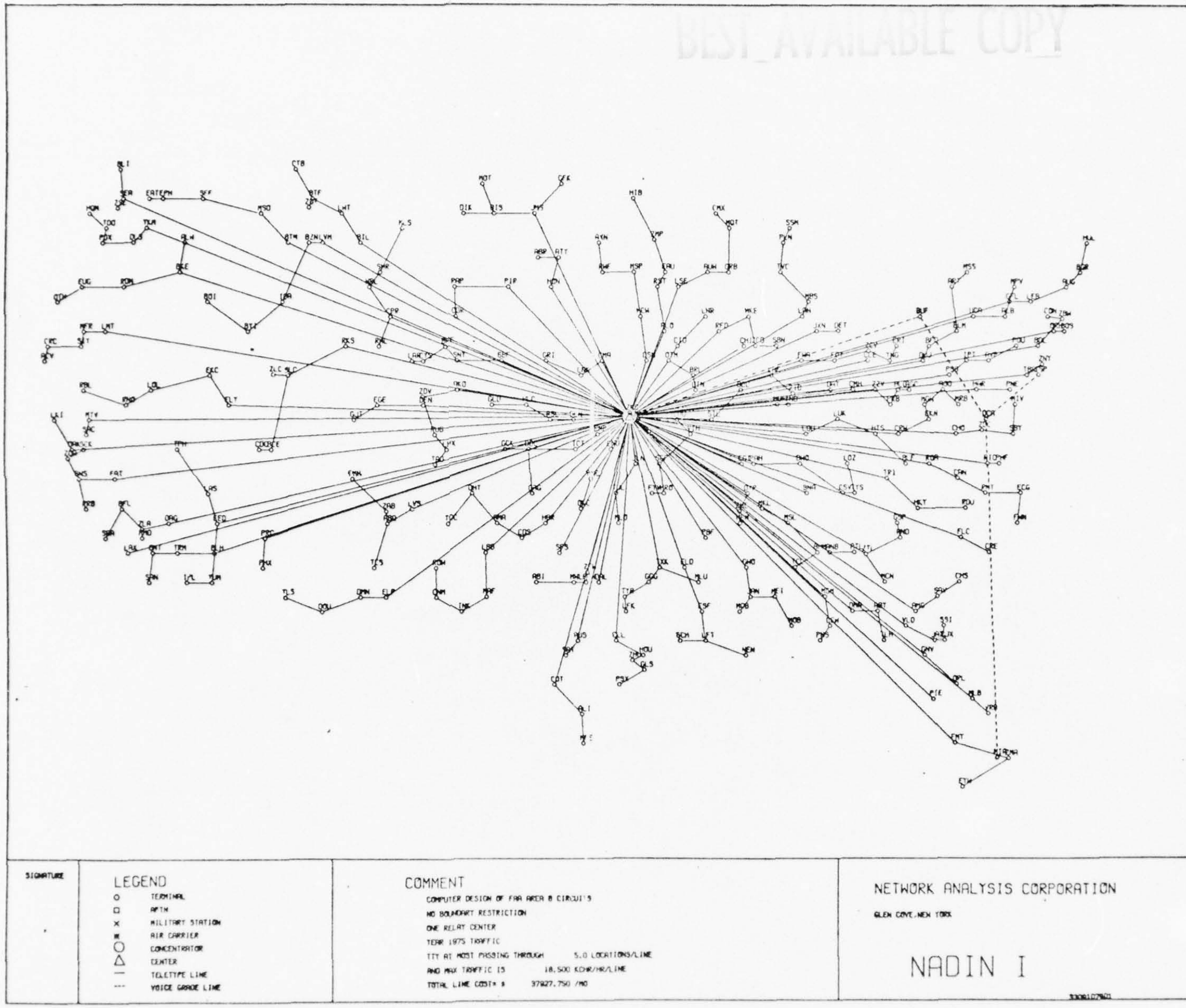

BEST AVAILABLE COPY
SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
NO BOUNDARY RESTRICTION
ONE RELAY CENTER
TERM 1975 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18,500 KCHR/HR/LINE
TOTAL LINE COST= $ 37827.750 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-2

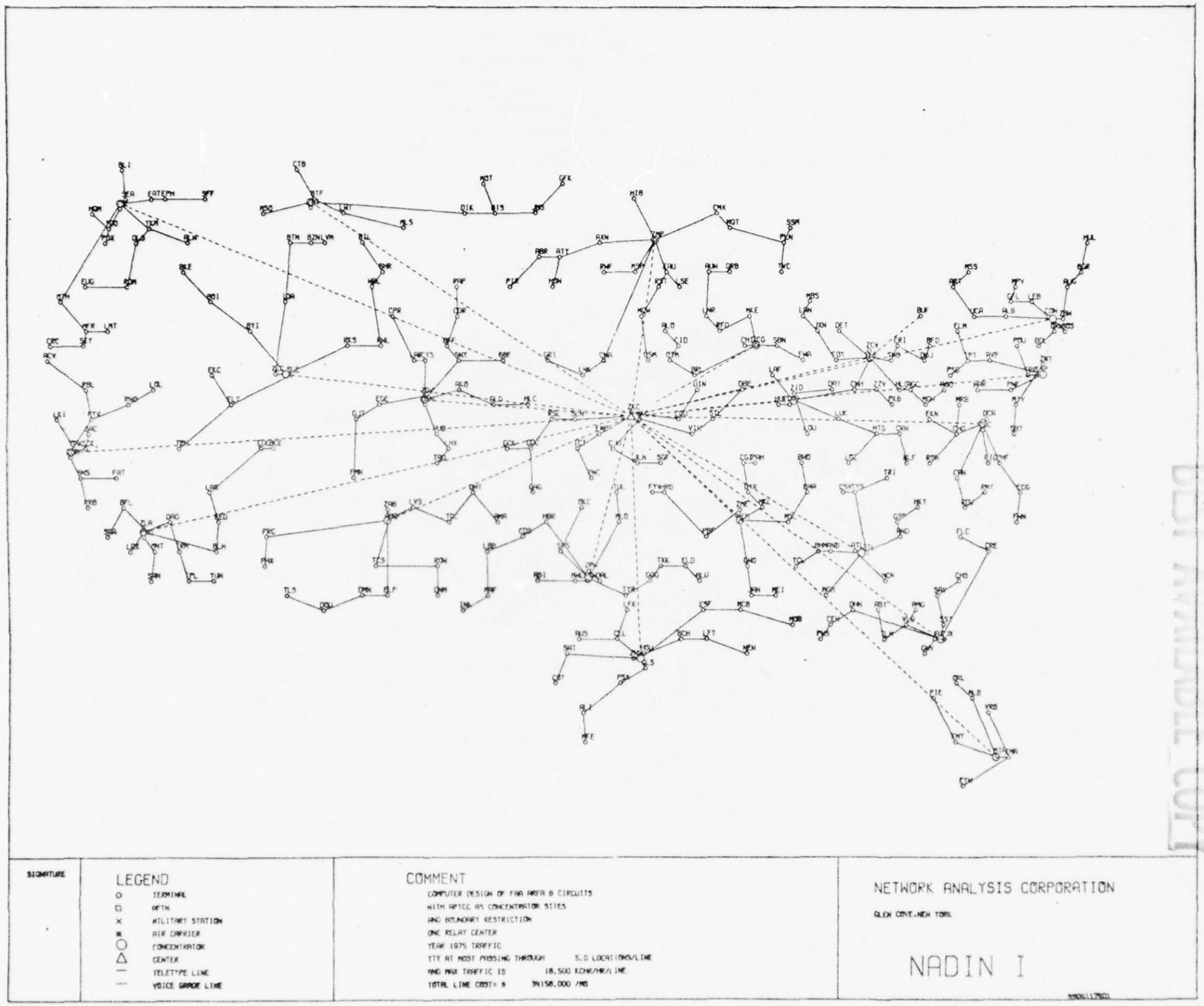

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND BOUNDARY RESTRICTION
ONE RELAY CENTER
YEAR 1975 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18,500 KCHR/HR/LINE
TOTAL LINE COST= $ 34158,000 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-3

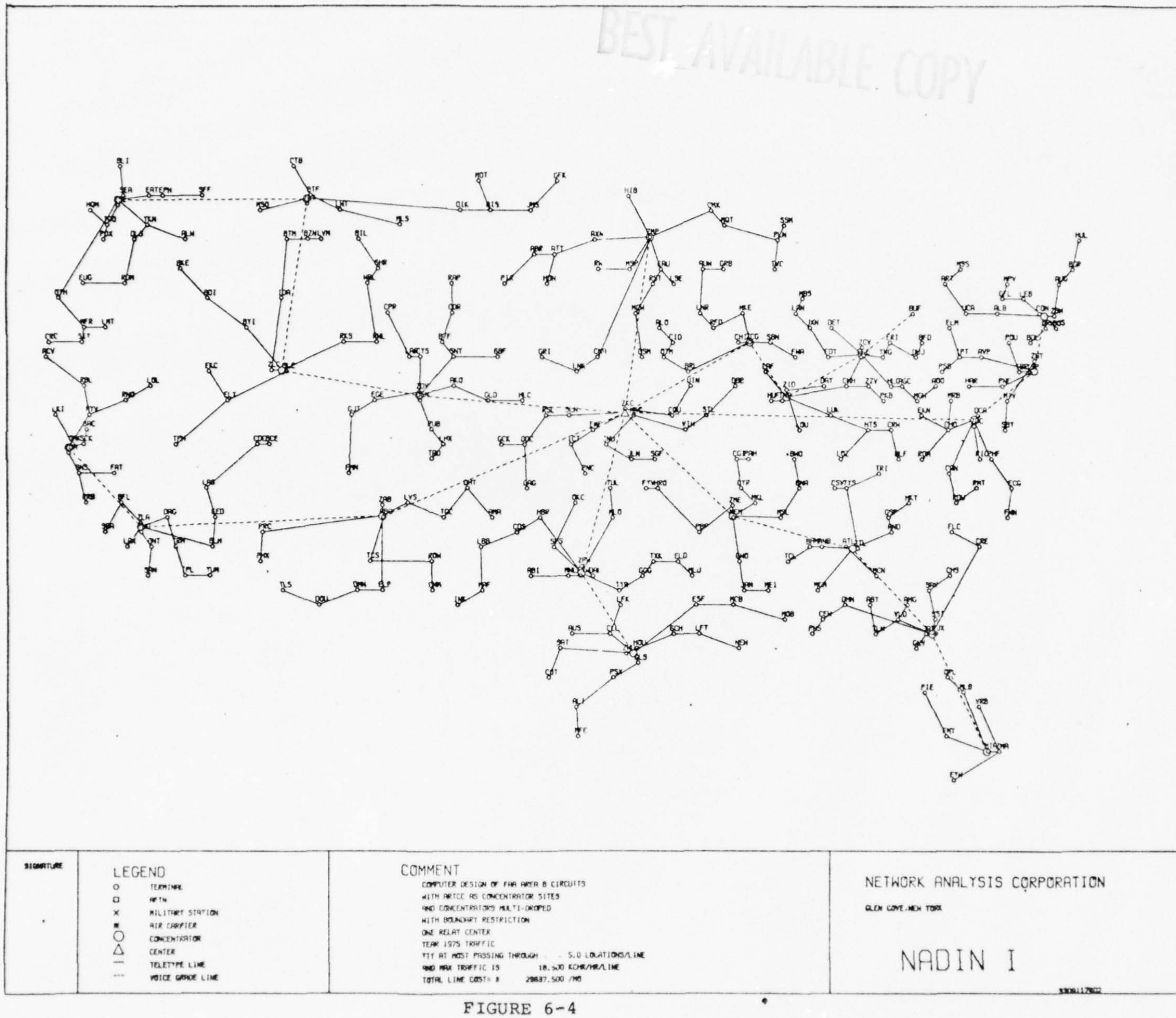

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPED
WITH BOUNDARY RESTRICTION
ONE RELAY CENTER
YEAR 1975 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18.500 KCHR/HR/LINE
TOTAL LINE COST= $ 29837.500 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-4

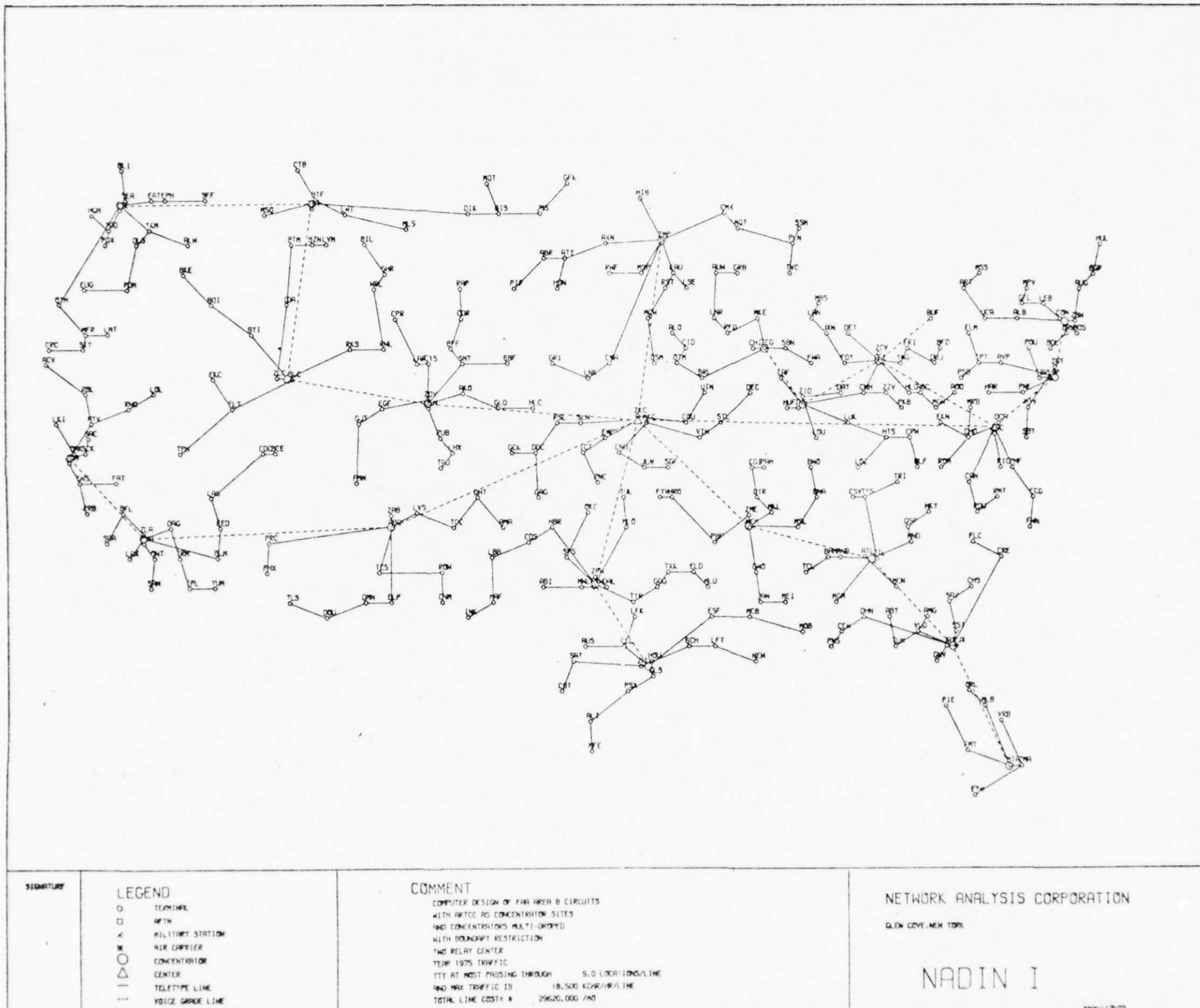

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPPED
WITH BOUNDARY RESTRICTION
TWO RELAY CENTER
YEAR 1975 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18,500 KCHAR/HR/LINE
TOTAL LINE COST= $ 29620,000 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-5

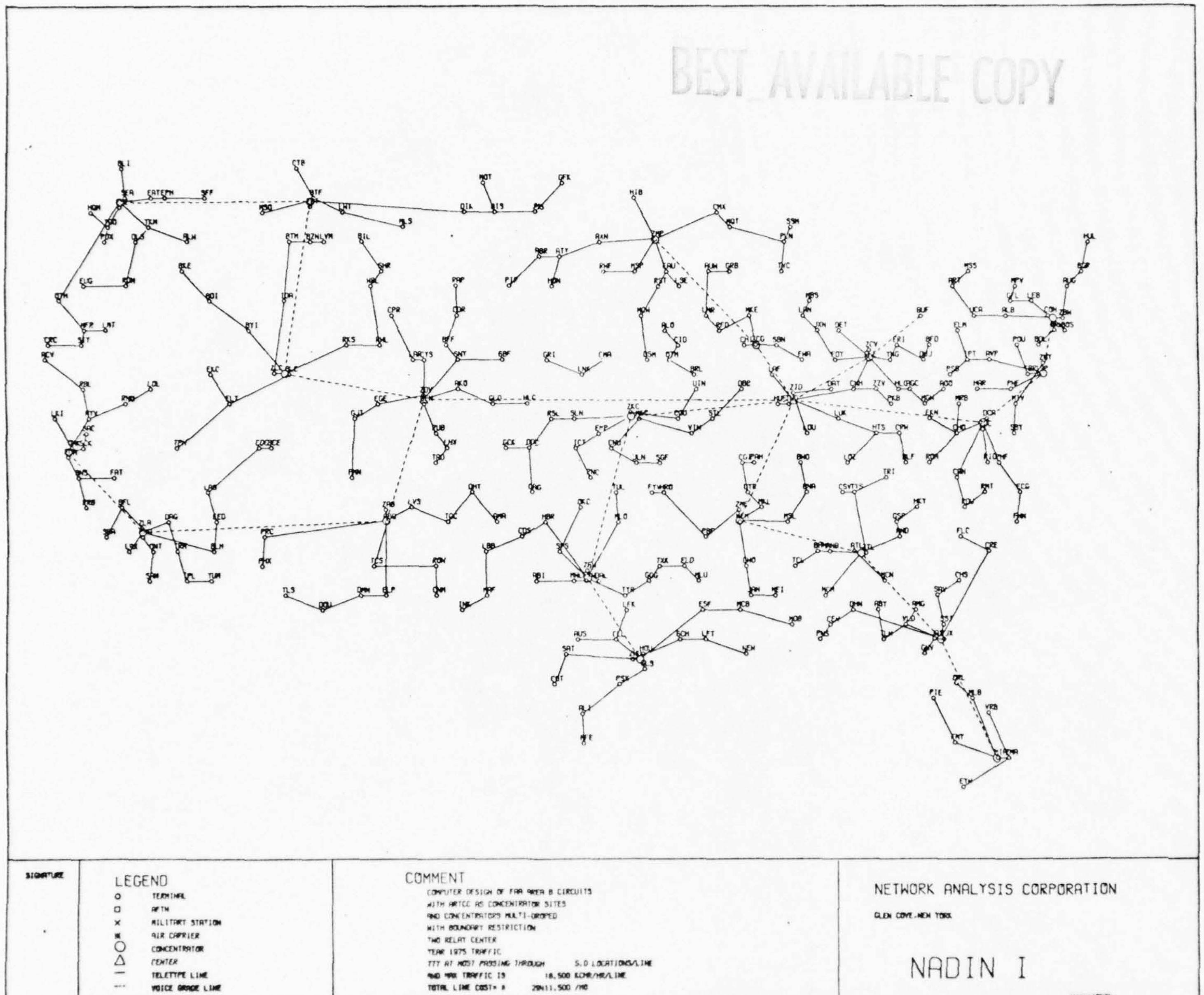
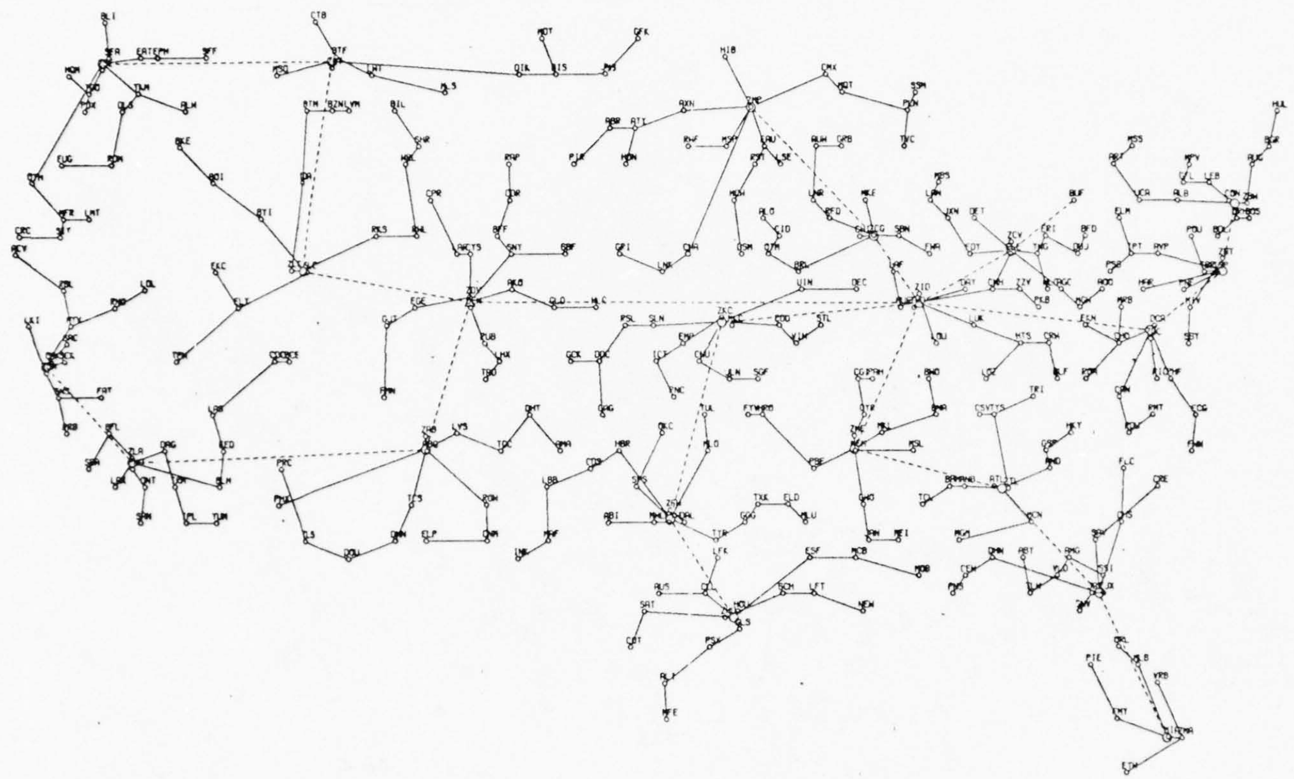

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPED
WITH BOUNDARY RESTRICTION
TWO RELAY CENTER
YEAR 1975 TRAFFIC
??? AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18,500 KCHR/HR/LINE
TOTAL LINE COST= $ 29411,500 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-6



SIGNATURE

LEGEND
- ○ TERMINAL
- □ AFTN
- × MILITARY STATION
- ■ AIR CARRIER
- ◯ CONCENTRATOR
- △ CENTER
- — TELETYPE LINE
- --- VOICE GRADE LINE

COMMENT

COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPPED
WITH BOUNDARY RESTRICTION
TWO RELAY CENTER
YEAR 1977 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18.500 KCHR/HR/LINE
TOTAL LINE COST= $ 29718.750 /MO

NETWORK ANALYSIS CORPORATION

GLEN COVE-NEW YORK

NADIN I

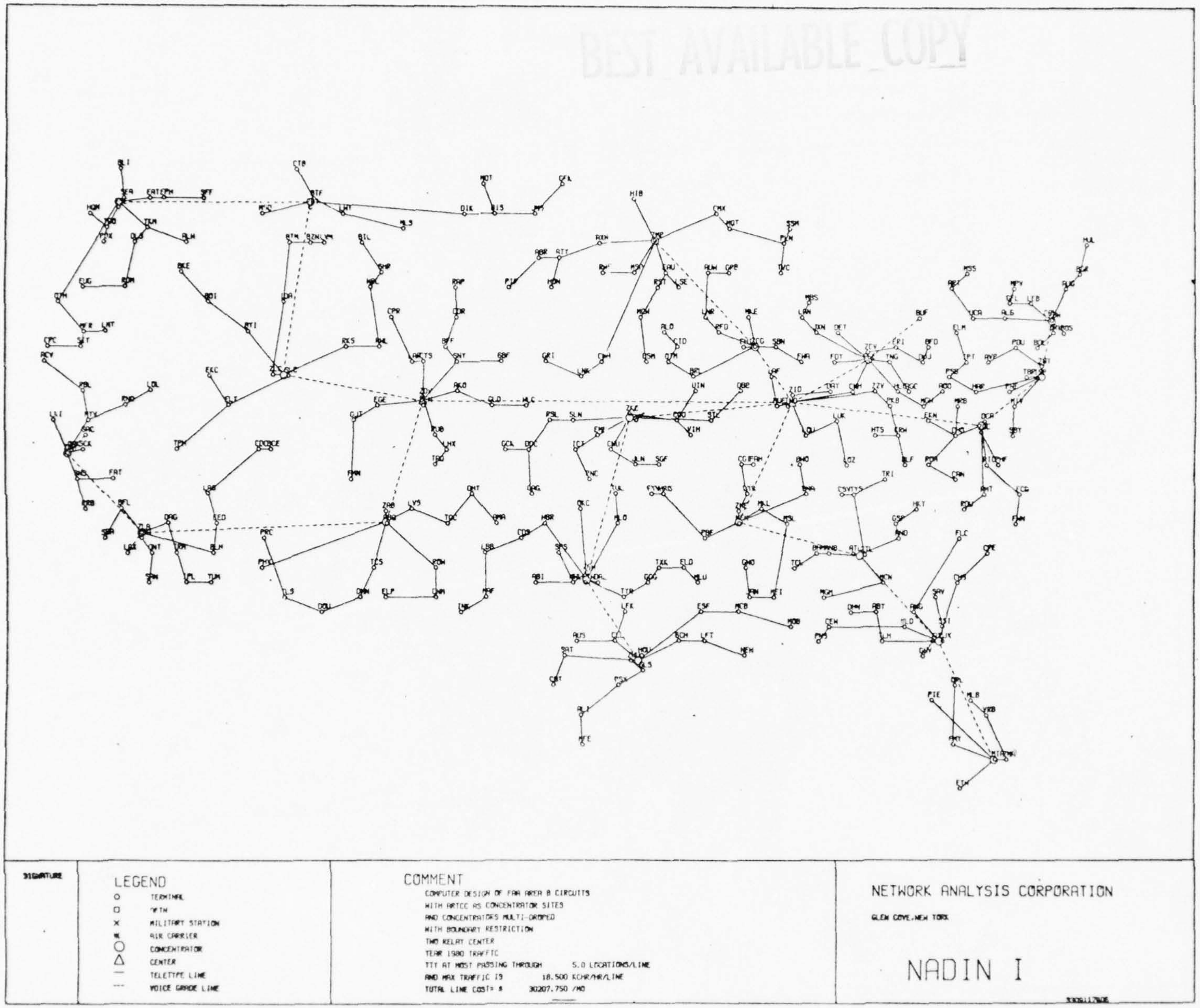
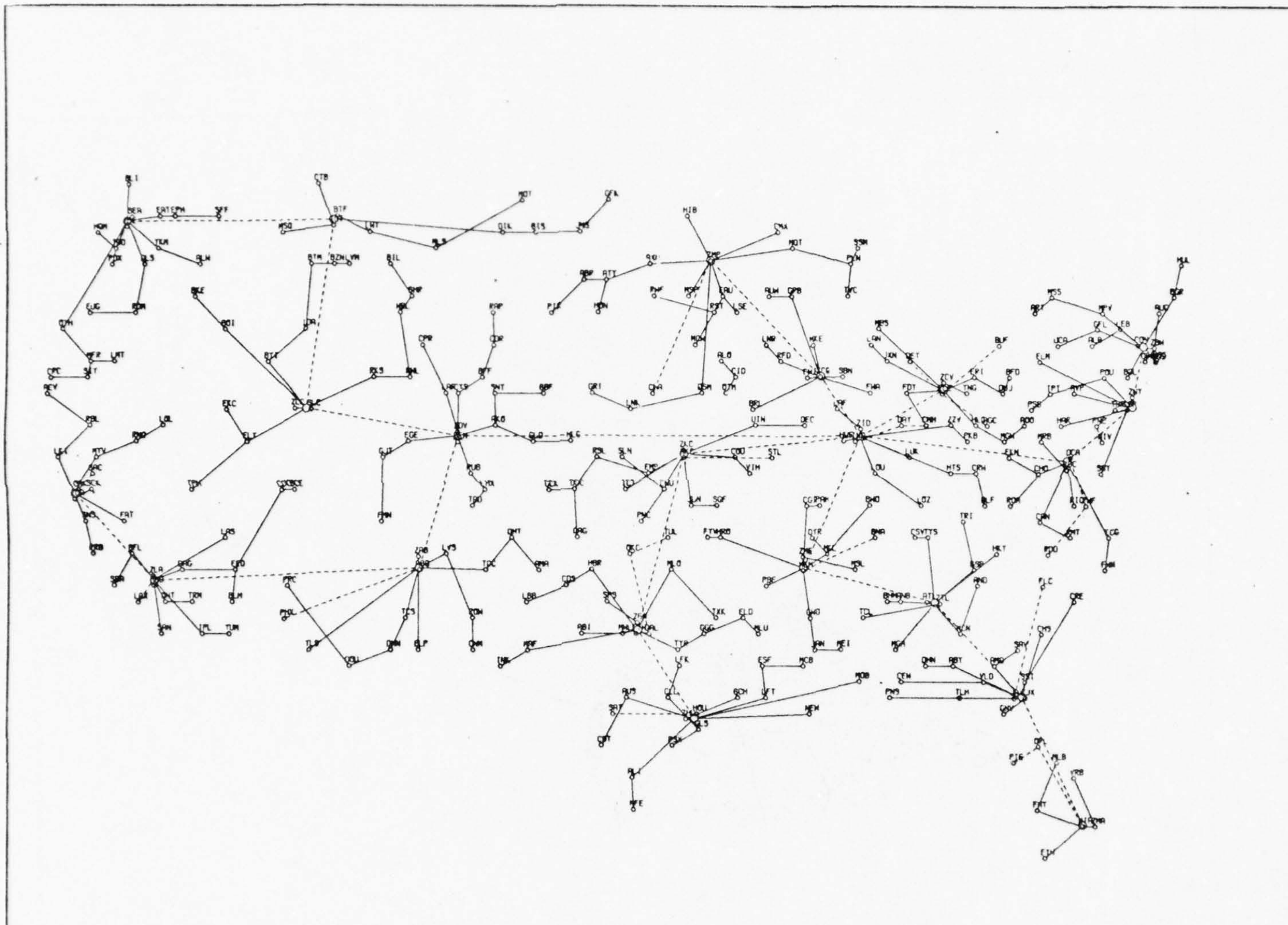

BEST AVAILABLE COPY
SIGNATURE
LEGEND
TERMINAL
WTH
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPED
WITH BOUNDARY RESTRICTION
TWO RELAY CENTER
YEAR 1980 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18.500 KCHR/HR/LINE
TOTAL LINE COST= $ 30207.750 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-8



SIGNATURE	LEGEND	COMMENT	
	○ TERMINAL □ AFTN × MILITARY STATION ✱ AIR CARRIER ◯ CONCENTRATOR △ CENTER — TELETYPE LINE --- VOICE GRADE LINE	COMPUTER DESIGN OF FAA AREA B CIRCUITS WITH ARTCC AS CONCENTRATOR SITES AND CONCENTRATORS MULTI-DROPPED WITH BOUNDARY RESTRICTION TWO RELAY CENTER YEAR 1984 TRAFFIC TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE AND MAX TRAFFIC IS 18.500 KCHR/HR/LINE TOTAL LINE COST= $ 33704.250 /MO	NETWORK ANALYSIS CORPORATION GLEN COVE, NEW YORK NADIN I

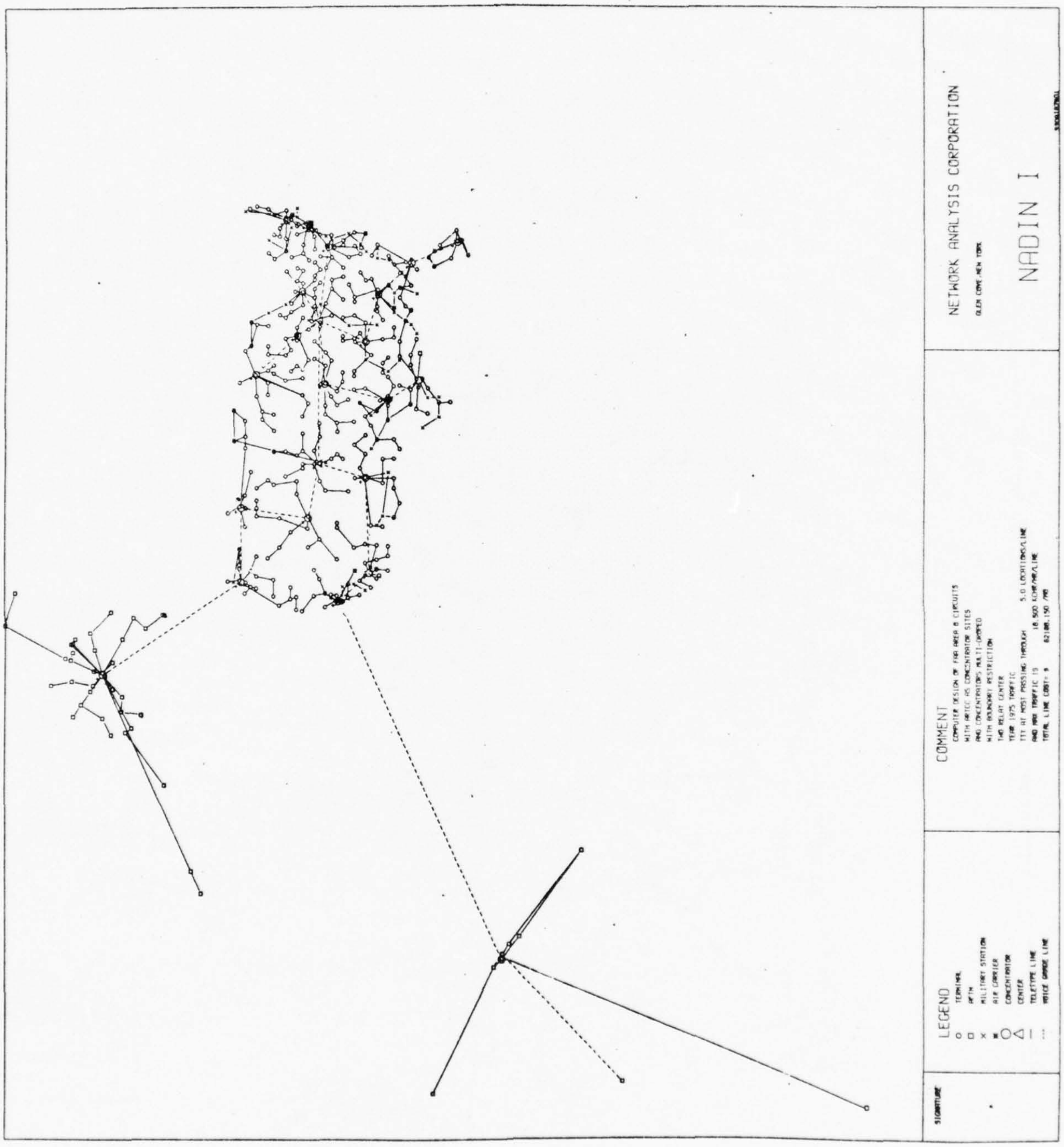

NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPPED
WITH BOUNDARY RESTRICTION
TWO RELAY CENTER
YEAR 1975 TRAFFIC
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 16.500 KCHR/HR/LINE
TOTAL LINE COST= 62188.150 /MO
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
SIGNATURE

FIGURE 6-11A

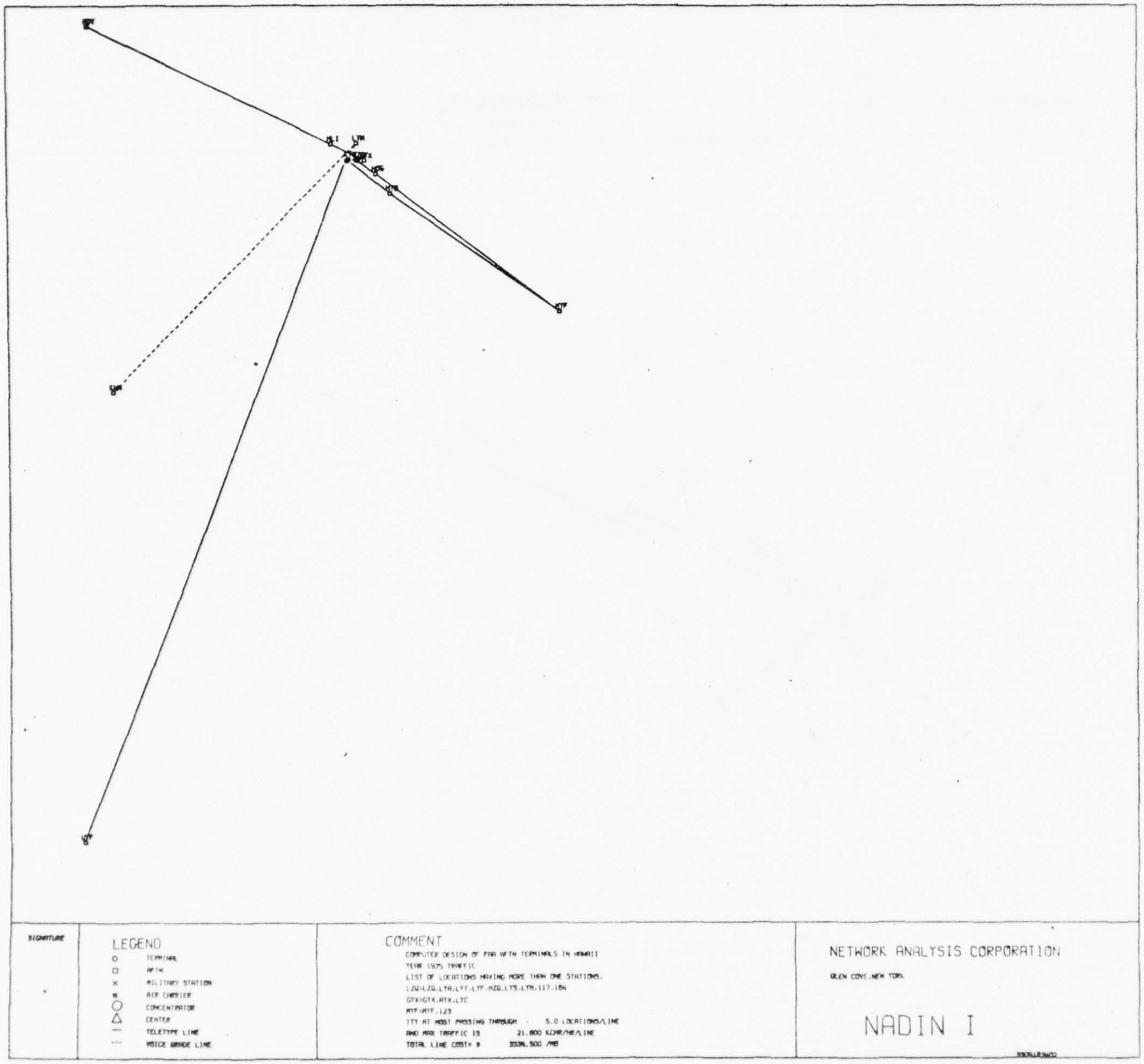

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AFTN TERMINALS IN HAWAII
YEAR 1975 TRAFFIC
LIST OF LOCATIONS HAVING MORE THAN ONE STATIONS.
LZQ:LZQ,LTA,LYY,LTF,HZQ,LTS,LTM,117,184
GTX:GTX,ATX,LTC
MTF:MTF,123
TTY AT MOST PASSING THROUGH - 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 21.800 KCHR/HR/LINE
TOTAL LINE COST= $ 3336.500 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE,NEW YORK
NADIN I

FIGURE 6-11B

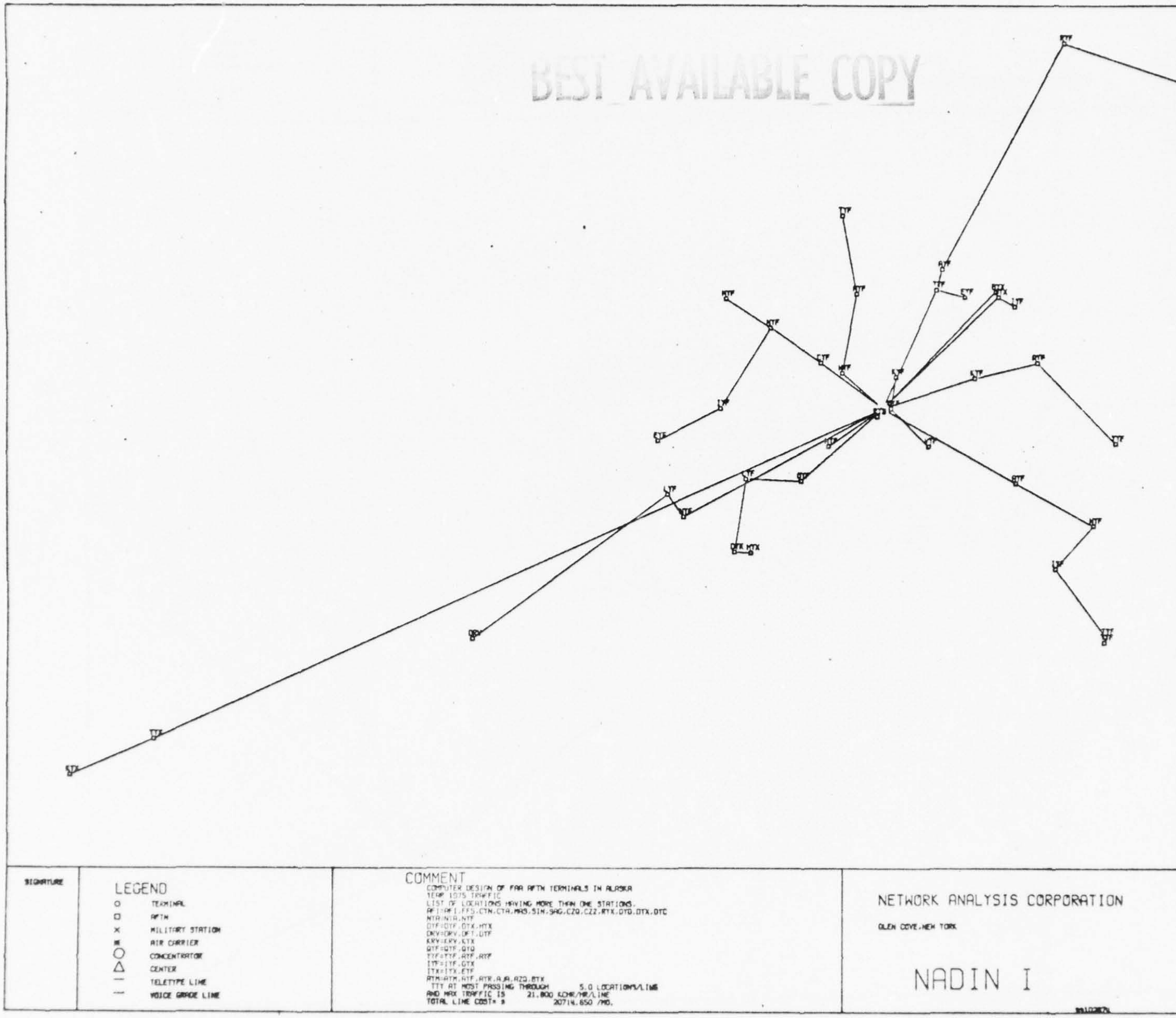

SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AFTN TERMINALS IN ALASKA
TERP 1975 TRAFFIC
LIST OF LOCATIONS HAVING MORE THAN ONE STATIONS.
AFI=AFI.FFS.CTN.CTA.MRS.SIN.SAG.CZQ.CZZ.RTX.DYD.DTX.DTC
NTA=NTA.NTF
DYF=DYF.DTX.HYX
DRY=DRY.DFT.DTF
KRY=KRY.KTX
QTF=QTF.QYQ
TYF=TYF.AYF.AYF
ITF=IYF.GTX
ITX=ITX.ETF
ATM=ATM.AYF.ATR.AJA.AZQ.BTX
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 21.800 KCHR/HR/LINE
TOTAL LINE COST= $ 20714.650 /MO.
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-11C

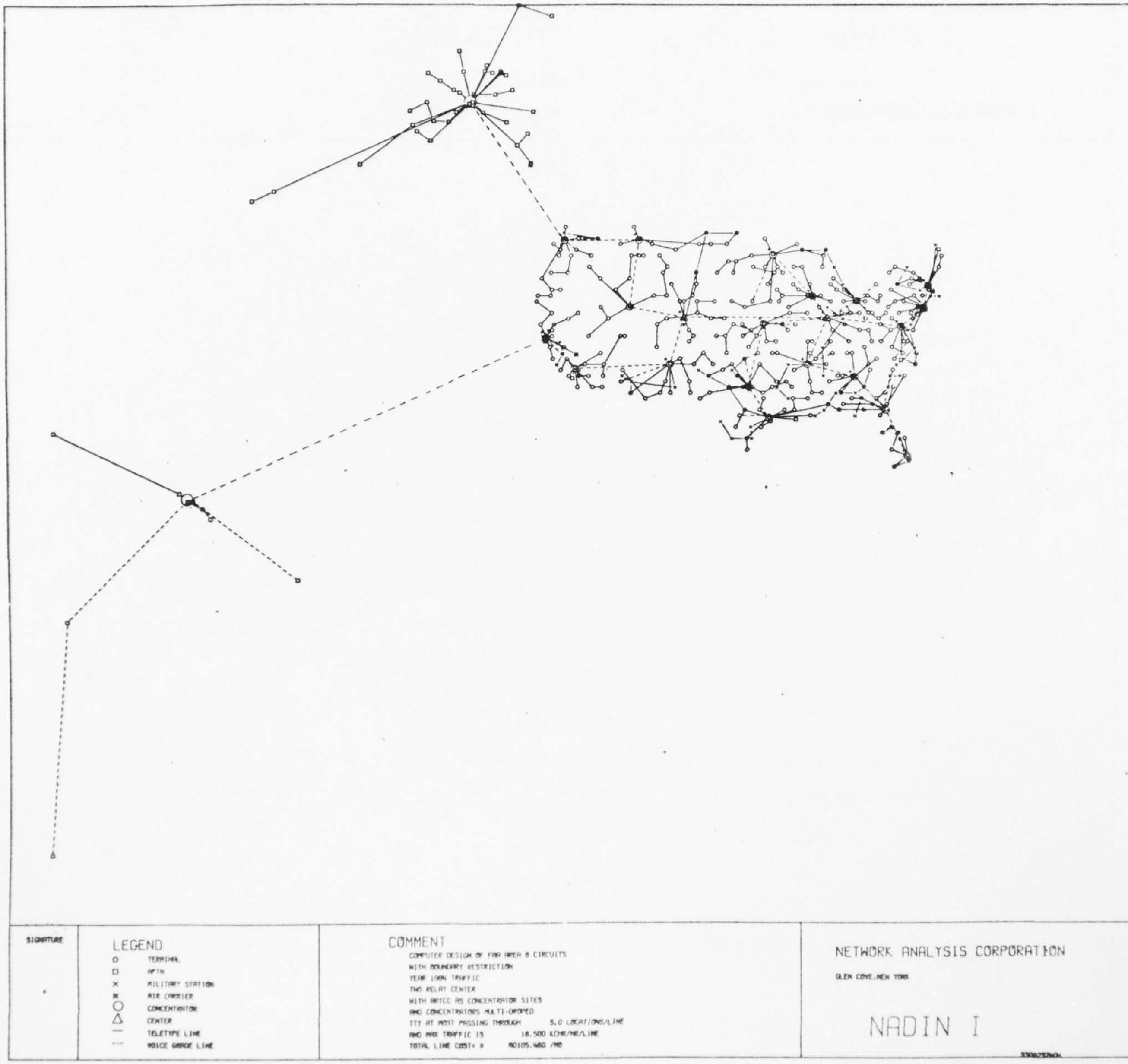

SIGNATURE
LEGEND
o TERMINAL
□ AFTN
× MILITARY STATION
AIR CARRIER
○ CONCENTRATOR
△ CENTER
— TELETYPE LINE
--- VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AREA B CIRCUITS
WITH BOUNDARY RESTRICTION
YEAR 1984 TRAFFIC
TWO RELAY CENTER
WITH ARTCC AS CONCENTRATOR SITES
AND CONCENTRATORS MULTI-DROPED
TTY AT MOST PASSING THROUGH 5.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 18.500 KCHR/HR/LINE
TOTAL LINE COST= $ 80105.480 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-12A

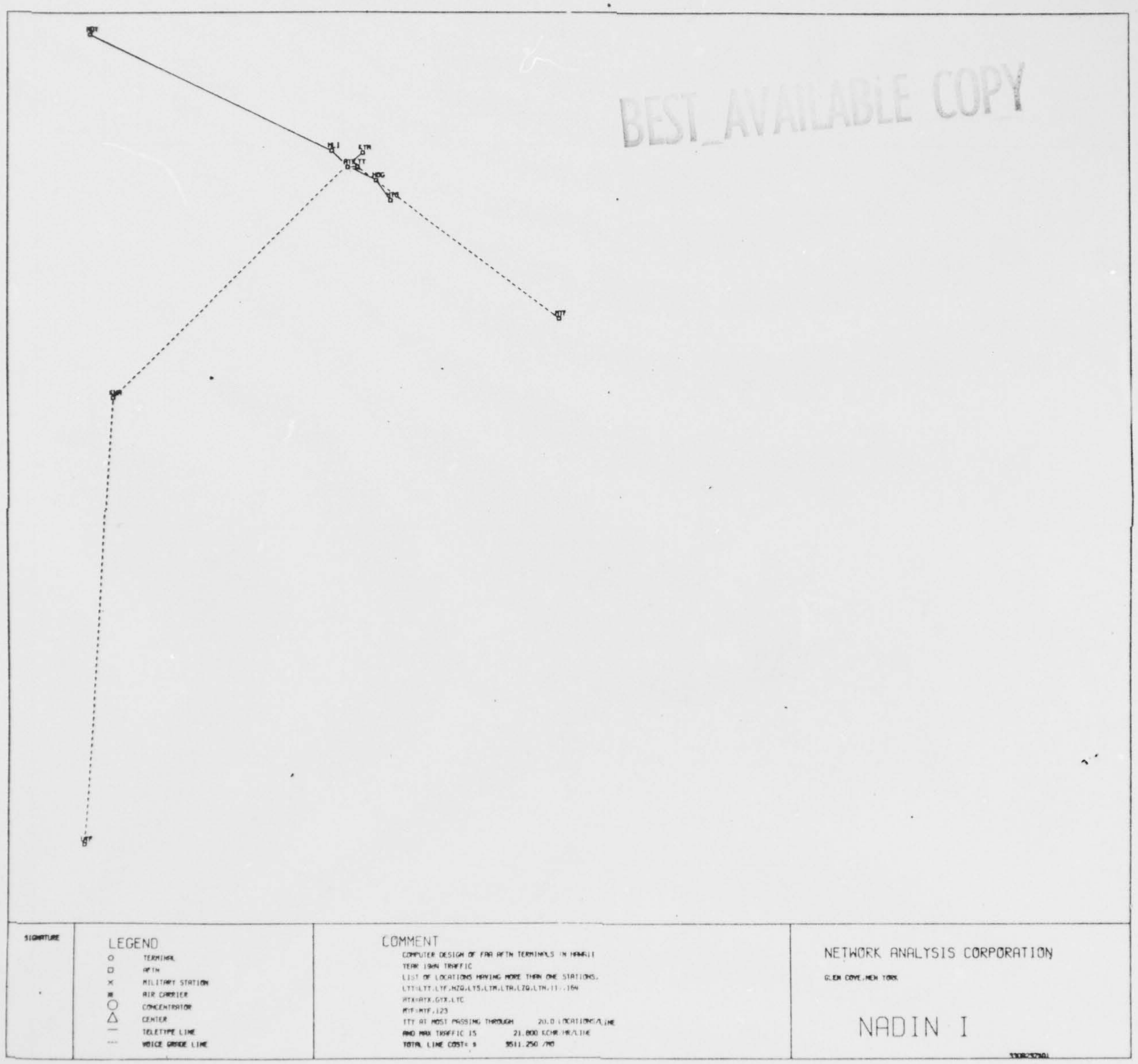

BEST_AVAILABLE COPY
SIGNATURE
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
COMPUTER DESIGN OF FAA AFTN TERMINALS IN HAWAII
YEAR 1984 TRAFFIC
LIST OF LOCATIONS HAVING MORE THAN ONE STATIONS.
LTT:LTT.LYF.HZQ.LYS.LTM.LTR.LZQ.LTN.11..164
ATX=ATX.GYX.LTC
MTF:MTF.123
TTY AT MOST PASSING THROUGH 20.0 LOCATIONS/LINE
AND MAX TRAFFIC IS 21.800 KCHR/HR/LINE
TOTAL LINE COST= $ 5511.250 /MO
NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I

FIGURE 6-12B

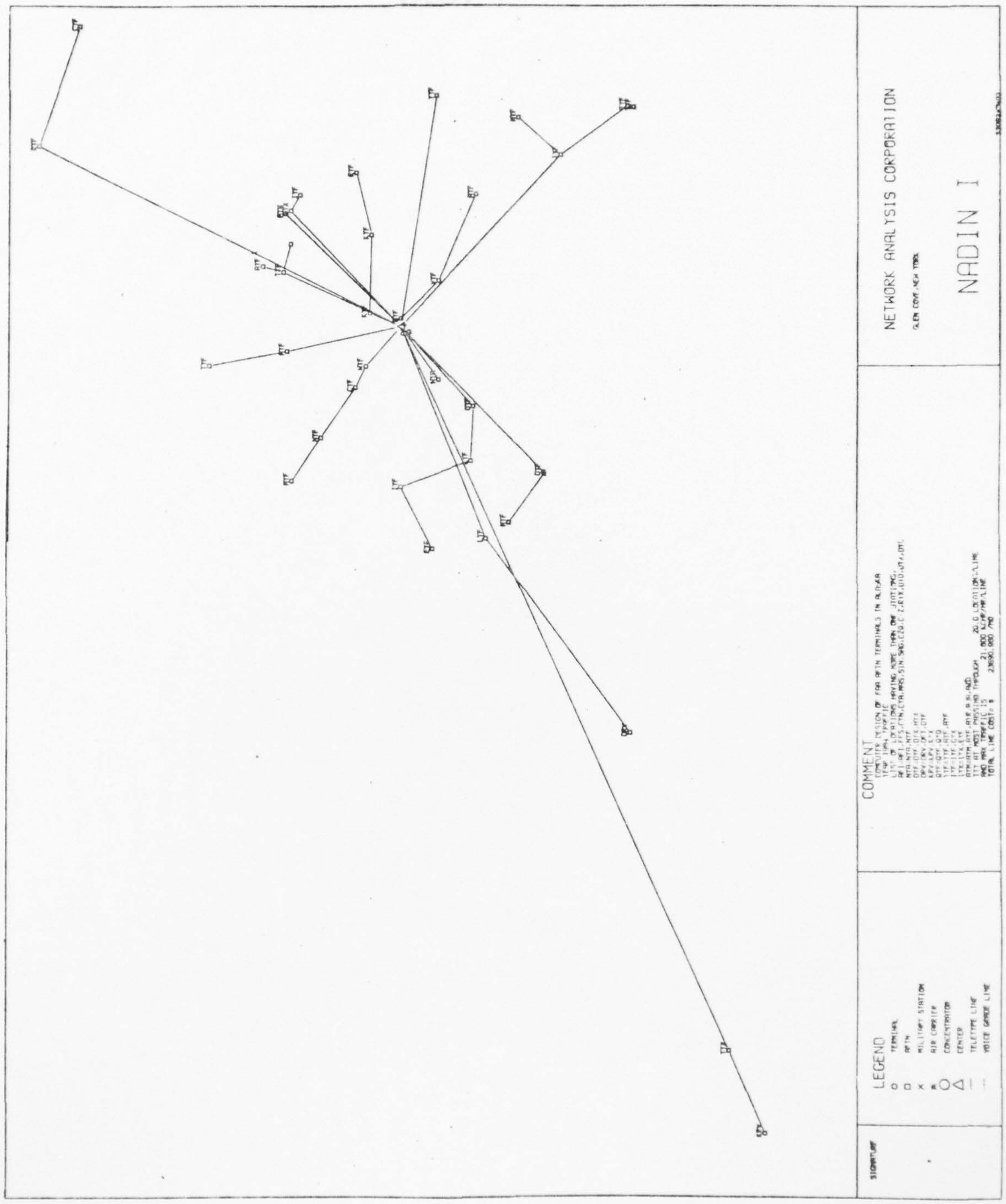

NETWORK ANALYSIS CORPORATION
GLEN COVE, NEW YORK
NADIN I
LEGEND
TERMINAL
AFTN
MILITARY STATION
AIR CARRIER
CONCENTRATOR
CENTER
TELETYPE LINE
VOICE GRADE LINE
COMMENT
SIGNATURE

FIGURE 6-12C

SECTION 7

CONCLUSIONS

7.1 SUMMARY

In this study the feasibility of cost-effective improvement of Service B and AFTN by integration has been examined and a network architecture has been developed which not only demonstrates the feasibility of satisfying the basic improvement objectives, but which may also serve as the kernal for continued NADIN development. The designs developed as part of the study illustrate particular attributes of the architectures being considered. The designs do not necessarily reflect the appropriate evolutionary stages of network implementation. These stages are the subject of continued study.

This section reviews the major findings of the study and attempts to assess the meaning of each finding to the network designer and the network manager. In those cases where the findings state that the network is relatively insensitive to the attribute in question, the interpretation to the network designer is "wider latitude in design" and to the network manager a non-critical item. Conversely, if the study reveals that the network is very sensitive to an attribute, both the network designer and manager have been alerted and they can provide the attention warranted.

7.2 OPERATIONAL REQUIREMENTS

The NADIN network not only meets all the operational requirements presently being satisfied by the Service B and AFTN networks independently, but it will be more cost-effective, provide for greater throughput, and reduce message delay time as shown in this study. Thus, it may be concluded

that for the immediate future, NADIN can and should replace the two independent networks - Service B and AFTN; the immediate benefits alone justifying the action.

More difficult to answer is the question, "Is NADIN the proper network for the FAA requirements of the 1980's?" In trying to answer that question, Telcom and NAC were faced with trying to ascertain and then quantify the 1985 FAA communication requirements suitable for integration into NADIN. In any requirements study, there are degrees of uncertainty that can be associated with any set of requirements. These sets of requirements may be organized into the following categories:

1. Existing requirements,
2. Quantified new requirements,
3. Potential new requirements,
4. Unknown new requirements.

The first category is the easiest to project into future requirements. Basically, it is a matter of predicting the growth of the existing requirements. For this study, the contractor primarily relied on the FAA aviation forecasts. Difficulties that occur are caused not by the analyst's inability to relate the new requirements to some growth factor (e.g., new message type as a function of flight plans), but by his inability to predict the user's reaction. The users may totally reject the methodology employed to meet their requirements, or the methodology might provide such improved levels of service that the users must modify their business methods, thus begetting new requirements. In this study, the latter situation is anticipated by establishing network architecture that can accommodate a 25% increase over the 1984 projected traffic levels and still maintain acceptable service levels. (It should be noted that this study uses

a 90% growth factor in aviation between 1980 and 1984 in order to assure system expandability.) Through the aforementioned analysis, the contractor has endeavored to meet the first two categories of requirements.

The third category of requirements includes approved but not funded projects, projects currently under study, and current working papers. Some of these projects will have little or no effect on NADIN as their communications requirements are minimal. Other projects have potential communication requirements that individually would impose a throughput requirement of an order of magnitude greater than today's Service B traffic load or require service levels of between one and two orders of magnitude faster than is today provided in comparable message-oriented systems. If the system architect designed the network to handle the entire aggregate of potential new requirements, the network would be so large and expensive that, in all probability, it would not be cost-effective in the short term. The network architect must provide cost-effective networks at implementation time, yet the network must be able to meet those "potential" new requirements that are implemented within the life cycle of the system design. The same is true of category 4 requirements. The study contractor has accommodated category 3 and 4 requirements by providing for both horizontal and vertical growth. This growth is more than the conventional growth obtained by adding more circuits, faster circuits, more terminals, faster terminals, more concentrators, larger switches, etc. The growth is also in new functions primarily obtained by the inherent flexibility and modularity of the concentrators.

7.3 NETWORK ARCHITECTURE

After reviewing the NADIN architecture, especially the maps and cost tables, one can reach several fundamental conclusions. The following paragraphs address each conclusion and discuss its impact on the network manager and designer.

7.3.1 Switching Center Location

This study concludes that the network cost is rather insensitive to the location of the switching center(s). To the network designer, it allows almost complete freedom to locate the switching centers. To the network manager, it relieves him of having to consider network costs in making a site selection. The network manager is free to consider only other factors such as the availability of space, personnel and other resources.

7.3.2 Quantity of Switching Centers

The study concludes that the least costly network architecture contains only one switching center node. To the network designer, a one-node network is also the simplest to design. However, the network manager must be concerned with survivability. To provide survivability, a two-node network is recommended in this study. The network manager does have a cost tradeoff decision to make - survivability versus minimum cost. It is noted that in many commercial applications, communicators have chosen the single-node architecture and hence minimum cost.

7.3.3 Non-CONUS Locations

The study concludes that non-switching concentrators should be placed at Honolulu, Anchorage and Puerto Rico. The conclusions are based on the assumption that journalling will be a requirement for locally switched traffic and that local switching does not add significantly to the reliability.

The network manager could choose to locate minor switching centers at these locations to provide local switching and journalling, but it would be an increased network cost that does not appear to be cost-beneficial.

7.4 DESIGN EFFECTS

There are two significant design areas that are affected by the network architecture. One is the choice of concentration techniques, the other is the impact of integration on operational compatibility. Each of these areas is discussed further.

7.4.1 Concentration

The study concludes that it is advantageous to choose concentrators over multiplexers for the NADIN network. The conclusion is based on the fact that concentrators provide significantly greater reliability and flexibility over multiplexers for about the same cost. This mainly affects the designer. However, the network manager should be particularly interested in the flexibility of the concentrator, for it is by this flexibility that the NADIN can accommodate horizontal growth of requirements.

As other requirements and possibly services are integrated into NADIN, it may be cost-effective to use multiplexers between the concentrator node and terminal locations, especially where there are several terminals located at or near the same service location. There is nothing in this study that precludes the designer from recommending and utilizing multiplexers (either TDM or FDM) if the situation warrants.

7.4.2 Operational Compatibility

The study recommends the integration of the Service B and AFTN networks, while at the same time pointing out 12 categories of terminals. The categories are caused by:

- Inconsistent line protocols,
- Inconsistent formats,
- Agency privacy requirements,
- Geographic dispersion.

The network manager must, as a minimum, prevent the formulation of unnecessary categories of terminals and, consistent with changes in operating requirements, work toward the reduction of the number of terminal categories. The adoption of a NADIN format designed for flexibility is one possible step to eliminate incompatible category proliferation.

7.5 ECONOMIC CONSIDERATIONS

After ascertaining that NADIN meets the FAA's operational requirements during the period 1975-1985, the next most important subject is the economic benefits derived from the network.

7.5.1 Immediate Savings

The study concludes that immediate savings can be realized as soon as NADIN is implemented, due to the reduction in network costs. Additionally, it appears that further savings could be realized within the first two years of operation as obsolescent facilities (mainly relay centers) are closed or consolidated.

7.5.2 Growth

The study concludes that the NADIN network can be designed so as to grow modularly with requirements. This reduces initial investment costs. It also provides the network manager and designer with flexibility to meet new requirements. Probably the most important factor in a modular growth plan is that the manager does not have to make all implementation decisions initially, but can make these decisions over the entire life of the system, benefiting from operational feedback information.

SECTION 8

ADDITIONAL CONSIDERATIONS

8.1 INTRODUCTION

It has been shown that a combination of the Service B and AFTN networks into a single NADIN network would provide more effective service at less overall cost. Integration considerations involve the successful operation of the new network with a minimal effect on operating personnel and existing terminal equipment carried over from the predecessor networks. There is also the matter of system integration wholly within the new network. It must be designed to be self-consistent and operable under all of the conditions to which it may be subjected.

In this section, consideration is given to some of the factors beyond system architecture that affect system design. Detailed consideration is beyond the scope of the study reported herein. However, these matters must ultimately be considered in a unified manner and in detail. The performance and cost of the system depend upon the switches, concentrators, terminals, transmission facilities, personnel and the interactions between these elements. Decisions on various systems parameters cannot be made in isolation but must consider all of the system ramifications. The present Service B and AFTN networks have evolved as needs dictated. The networks have worked well and served their purpose. However, the design of an integrated NADIN provides an opportunity to re-examine and evaluate all of the factors inherent in a system design and to set an even higher standard of efficiency for future operations.

8.2 LINK CONSIDERATIONS

8.2.1 Error Control Procedures

Interference and transmission anomalies can cause intended coded symbols to be translated into unintended symbols. As a result, message garbles may occur, or overprinting of a message may take place. The process of error control is intended to prevent these effects from becoming intolerable.

A basis for automatic error detection is the transmission of redundant bits along with the information bits in a message. The resulting bit patterns are designed so that transmission disturbances are more likely to be translated into illegal bit patterns than into those patterns that are considered valid message material. It is evident that with error detection the number of bits transmitted in a message is greater than the number of bits required to transmit only the information.

8.2.1.1 Error Detection With Five Level Code

If we consider each letter of the alphabet, each single digit number, essential punctuation marks, and a minimum number of control functions such as carriage return and line feed, we find that 40 characters and functions are needed. A five-bit code is capable of producing only 32 character combinations (i.e. symbols, letters, numbers, punctuation marks, and control codes). By the use of figure and letter shift symbols, it is possible to represent as many as 60 characters with a 5-bit code. Clearly, there are few redundant bits in such an arrangement. For this reason, five-level teleprinter circuits have not been designed with automatic error detection and correction capability. In such cases, it is left to the recipient to detect errors in the message. Symbol transpositions are detected because of the recipient's prior knowledge of the general sense of the message, or because of the redundancy inherent in language text. Data and pure numerical information are not easily amenable to visual error detection by the recipient. Where

numerical data are not a significant fraction of the traffic, data redundancy within the text can be provided so that the recipient can detect errors. This can be accomplished by repeating the data within the message. It can also be accomplished by spelling numerals. A more elaborate approach, which is useful where automatic data processing equipment is available, is to transmit data check characters or sequences derived from the data being transmitted and constructed in a predesignated manner. The data processing equipment at the receiving station also derives the data check sequence from the received data and then compares the transmitted and received check sequences. A discrepancy indicates that a transmission error has occurred.

All of the preceding techniques are designed to overcome the error detecting deficiency of five-level code. Ingenious methods have been devised for automatic error detection with five-level terminal equipment. This has involved use of the start and stop intervals for adding redundant bits to each character. Characters are then usually transmitted in blocks resulting in a pseudo-synchronous transmission mode. One method uses a 7 bit fixed length character code which always has exactly three marks for each symbol. It is readily seen that this permits the transmission of 128 symbols, only 35 of which are legal. Accordingly, a measure of redundancy is obtained.

8.2.1.2 <u>Error Detection With Seven-Level Code</u>

Seven-level equipment is usually designed so that an eighth level is provided for a parity (redundant) bit. This provides for transmitting 256 symbols, only 128 of which are valid. The use of a 128 symbol character set eliminates the need for figures and letters shift characters and permits

the use of additional valuable control symbols. When asynchronous transmission is used, the parity bit for each character is set so that the total number of marks in a character is always an even number (ANSI X 3.16 - 1966). The receiving equipment is designed to count the number of marks in each character. When parity is not achieved, the receiving printer may be configured to print a special character, such as an asterisk or a question mark, in place of the incorrect symbol. This aids the message recipient in detecting the presence of an error.

8.2.1.3 Error Correction

Error correction is generally considered to be of two types: manual and automatic. For most asynchronous transmission applications involving reliable circuits, communicators have depended upon the recipient to initiate a manual service request for retransmission. When the circuits were excessively noisy, communicators employed automatic reply-request (ARQ) on a character basis coupled with error detection (i.e., three-out-of-seven) techniques to improve the quality of information transfer. ARQ is the usual method of error correction performed with synchronous transmission. The error detection techniques commonly used are either longitudinal redundancy check (LRC) or cyclic redundancy check (CRC). In either case, a unique block check character sequence is constructed using information from all of the characters in the block. As an additional check, character parity may also be detected. At the receiving station, the block check sequence is reconstructed from the transmitted data and then compared with the received block check sequence. If they agree, a block acknowledgement signal is returned to the sending terminal. A discrepancy results in a request for retransmission of the block.

Another form of automatic error correction amenable to synchronous transmission is forward error correction (FEC). When forward error correction is used, sufficient redundancy must be present in each block transmission so that the occurrence of errors that alter the bit composition of the block does not prevent the association of the resulting erroneous bit pattern with the intended correct bit pattern. Thus, when forward error correction is used, the processing of an incorrect block at the receiving station not only detects the block errors but also corrects them. The number of redundant bits required for FEC is a function of the specified degree of error correction and may equal the number of information bits if a high degree of error correction capability is desired.

As a general rule, for transmissions over land lines and for radio transmissions where circuit noise is not excessive, ARQ error detection and correction is more common than forward error correction. For satellite transmission, where transmission delays are large, forward error correction may be desirable.

The foregoing discussion points up the merit of transmission which permits automatic error detection and correction to be employed and can result in virtually error-free messages in the hands of system users and operators. The penalty paid for this benefit is the cost for more complex terminal equipment.

8.2.2 Line Efficiency

An important consideration for communications lines is the rate of information transmission when allowance is made for the transmission of control characters and transmission delays. Line efficiency is an often neglected parameter. Frequently, system users who evaluate line efficiency find that a nominal 100 word per minute circuit operates at effective

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NETWORK ARCHITECTURE OF NATIONAL AIRSPACE DATA INTERCHANGE NETW--ETC(U)

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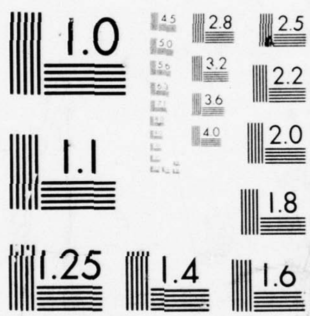

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0

rates of 50 to 60 words per minute. For this reason, switching system designers who specify line protocols must take pains to insure that no unnecessary delays are designed into circuit operating procedures. Low line efficiency is as great a threat to high-speed as to low-speed operation; careful design is needed in either case.

8.2.3 Quality Monitoring

On circuits using ARQ error control, monitoring of the circuit quality can be accomplished inexpensively at the switching center. The rate of retransmission can be related directly to circuit quality. On multi-point circuits, responses to polling signals constitute an on-line quality measuring means which is available at the switching center. Non-ARQ point-to-point circuits can be designed to send test messages (WRU) during idle periods that evoke automatic responses (answerbacks). These techniques all can be utilized by the computer switch to test circuit operability (continuity plus quality) without the expense of automatic technical control circuit monitoring equipment.

8.2.4 Accountability

Accountability procedures attempt to prevent loss of messages on a transmission link. A higher (and more desirable) degree of accountability immediately informs the sending terminal that the transmitted message has been received. Automatic message acknowledgement is readily performed by the computer message switch. That is, the switch will confirm to a message sender that it has satisfactorily received a message. Automatic message acknowledgement by a terminal is possible for advanced types of terminals, usually operating at higher speeds with ARQ error control procedures. When such procedures are not used, it is possible for the message switch to request response signals from

the receiving terminal before and after the message is transmitted. This assures circuit continuity at these times, but does not guarantee that the message has been received intact. The use of channel sequence numbers is a method used to insure that messages are not lost. At the message switch, the sequence number for received messages from any terminal is automatically checked for continuity. The occurrence of an out-of-sequence number will immediately be detected and cause an alarm or a service message. A similar check can be performed for messages received by a suitably designed terminal. Conventional asynchronous low speed terminals have no sequence number checking capability. It is necessary to rely on the operator to check sequence number continuity.

The message acknowledgement procedure is presently accomplished manually on Service B for some types of messages and on AFTN for priority SS messages only. Channel sequence numbers are used on the AFTN.

8.2.5 Survivability

Certain types of traffic, such as Air Traffic Control messages, must be successfully communicated in spite of link outages which occur at random throughout the network. For this type of traffic, the network must be designed with alternate paths to vital stations or with some other form of redundant circuit configuration.

8.3 TERMINAL CONSIDERATIONS

While the use of computer message switching allows terminals of differing speeds and codes to communicate, the network configuration restricts this latitude. On any single multi-point circuit, all terminals must operate with identical speeds and codes, and use the same line protocol. Therefore, if 7-level terminals are introduced while 5-level equipment is still in use, the new terminals must either be used on

single terminal circuits or must be segregated in multipoint circuits, excluding 5-level equipment.

Traffic volume will dictate whether point-to-point or multi-point operation is desirable. A spectrum of traffic volumes from very low to high can be accommodated in accordance with the following listing of circuit configurations.

a. Low speed asynchronous multipoint

b. Low speed asynchronous point-to-point

c. Medium speed asynchronous multipoint

d. Medium speed asynchronous point-to-point

e. High speed synchronous multipoint

f. High speed synchronous point-to-point

The cost of terminals usually increases with the speed of operation (An exception is the cathode ray tube terminal which is less costly than an equivalent low speed teleprinter, but does not produce hard copy output). High speed terminals are warranted when response time requirements are stringent or when traffic levels are high. The cost per bit of operating a single high speed terminal over a voice band circuit is less than operating a multitude of low speed terminals over 100 wpm circuits, provided the traffic loading on the high speed terminal is at an efficient level. Accordingly, as the traffic requirements of a single teleprinter equipped station increase, consideration should be given to replacement by a high speed terminal.

In some instances, multiple capabilities may be required in a terminal. That is, there may be a requirement for a cathode ray tube display, a high speed printer, and perhaps some capability to present message format cues to the terminal operator. While special terminals can be designed for such applications, consideration should be given to the use of a small mini-computer interface between the communications

line and the various terminal devices. This arrangement provides great flexibility in meeting present requirements as well as adapting to unanticipated future requirements. The use of an intelligent terminal (such as that described) has the advantage of relieving the computer message switch of the loading required to transmit format cues and other data which could be locally generated. This mini-computer interface approach also provides flexibility in permitting different commercially available terminal devices to be combined with the mini-computer to form a single multipurpose terminal of high capability.

The cost of terminals should not be considered in isolation, but should be viewed together with transmission, concentrator, switching and operator costs. The last is of particular concern, since it appears likely that operator costs are of the order of magnitude of transmission costs in a network. By utilizing the capabilities of the switch, the concentrators, and more modern terminals, there is the potential for reducing the operator workload and correspondingly reducing costs. As an example, much of the format material in a message, such as the SOM sequence, the sequence number, the originating station identifier, and the EOM sequence can be generated automatically. These items could be supplied by the sending terminal. However, in cases where modification or replacement of the sending terminal is not feasible, certain items can still be automatically provided by the concentrator. For example, the concentrator might supply channel sequence numbers on outgoing traffic and check for the continuity of channel sequence numbers on incoming traffic.

Thus, the design of the NADIN must consider the operators, terminals, concentrators, switches and transmission facilities as a system and optimize system performance at the lowest possible cost.

8.4 ADDRESSING AND ROUTING CONSIDERATIONS

8.4.1 Address Conventions

8.4.1.1 Service B

Service B currently uses a three-letter designator to indicate the addressee. The designator identifies the station addressed.

8.4.1.2 AFTN

AFTN uses a six or eight-letter designator as follows:

Letter	Identification
1st	Geographic area
2nd	Country
3rd and 4th	ICAO station letters
5th and 6th	Aircraft operating agencies, aeronautical authorities, and services
7th and 8th	Office code (if used)

8.4.1.3 Proposed NADIN

The proposed NADIN network must use an addressing scheme which preserves for AFTN operators the address conventions of that network since it operates in accordance with ICAO standards. Because of the computing capability available at the switches, concentrators, and (in some cases) terminals, it may be possible to reduce operator effort. Service B stations need not use an ICAO format, since Service B and ICAO stations will interconnect via a computer switch or concentrator that can perform address and format conversion. Even within the AFTN network, techniques are available for reducing the operator work load.

8.4.1.3.1 Explicit Addressing

When explicit addressing is used, the originating station by some means designates who the intended recipients

are. This has been the method used on both Service B and AFTN. There are methods available for potentially reducing operator work load.

8.4.1.3.1.1 Abbreviated Addressing

Many stations send messages only to a small sub-population of the network terminals. In such cases, abbreviated addresses are possible. Depending on where the nearest computing capacity is available, the terminal, the concentrator, or the message switch can be used to provide the complete address according to network standards. The responsible computing function will retain a table for each originating station giving the correspondence between the abbreviated address and the complete address designator.

8.4.1.3.1.2 Multiple Addresses

In the AFTN, multiple-address messages are restricted to a number of addresses that will not exceed one line of the message. Additional addresses require that a new message be composed. In NADIN, this restriction can be substantially relaxed. Multiple address messages with many lines of addresses can be sent to the message switch. There, the message can be recomposed according to ICAO standards and transmitted as several messages, each with only one line of addresses.

8.4.1.3.1.3 Address Stripping

When multiple address messages are transmitted on NADIN, the message switch can, if desired, strip all address designators from a transmitted message except the address to which it is being delivered. This reduces the times required to print and read the message and (for Service B) may reduce teleprinter paper consumption.

8.4.1.3.1.4 Group Codes

When certain groups of stations are frequently addressed in a multiple-address message, a group code can be

used instead of the individual addresses. The group codes are stored in the message switch which then generates the individual messages to each addressee. This procedure reduces operator effort and transmission time in sending such messages.

8.4.1.3.2 Implicit Addressing

In some cases, certain stations invariably send a message type to a specific station or other stations. Then it is not necessary to address the message. The addressees can be deduced from the originator identifier and the message type. The message switch has a table for each such originator, by message type, which contains the addresses for the message. On input to the message switch, the address for an implicitly addressed message need not be included. The output from the message switch will contain the message with the proper address inserted.

8.5 MESSAGE FORMAT

Since all messages will pass through a message switch, and since format conversion can be performed at the switch, it is not necessary to use a single format throughout the system. Although AFTN stations must continue to use the ICAO format, Service B is not so constrained. Therefore, the options for a NADIN format are shown in Table 8-1.

	NADIN	Service B Users	AFTN Users
1.	ICAO format	Service B format	ICAO format
2.	Service B format	Service B format	ICAO format
3.	ICAO format	ICAO format	ICAO format
4.	New format	New format	ICAO format

TABLE 8-1 MESSAGE FORMAT OPTIONS

Options 1 or 2 would have the least impact on the users. Option 3 would eliminate the need for format conversion. Both the Service B and the ICAO formats were designed with electro-mechanical and manual switching procedures as a background. Therefore, consideration should be given to the use of a new NADIN format designed to operate efficiently with more capable terminals and computer message switches, as well as with teleprinter terminals.

A new message format for NADIN would be required to achieve certain objectives as follows:

a. Operator interface

The new format should be easily read and used by the Service B operators (AFTN operators will see only the ICAO format). It should be designed so that it can be readily understood and does not require a substantial training effort.

b. Machine readability

The format must be designed with proper heading and ending delimiters so that it is machine readable, as are present Service B and ICAO formats.

c. Efficiency

The format should be designed to minimize the transmission time for a message.

d. Flexibility

The format should be expandable or contractable, depending on the application. It should be adaptable to many different message types including computer generated flight plans, weather collection, ARTCC messages, service messages, etc.

APPENDIX A

SYSTEM CONSTRAINTS

A.1. INTRODUCTION

The initial phase of the NADIN is to be a common user network serving the FAA data communication requirements currently being served by the AFTN and Service B network. Because these existing networks are well established, operational and highly utilized, they represent a significant operational investment in dollars and human resources. Their upgrading and integration in the initial phase of NADIN not only must be done as efficiently as possible through a smooth evolution of operational procedures and hardware transitions, but it must be done in a manner consistent with the basic objectives for NADIN. A guiding principle is therefore the use of existing facilities and operating procedures where such usage does not impair achievement of the communication requirements. In this section, several constraints for NADIN designs are developed on the basis of the above guiding principle and the following observations:

> The equipment characteristics and operating procedures for government and non-government terminals in the existing networks are not uniform, prohibiting indiscriminate placement of terminals on multidrop circuits.
>
> New terminals, operationally consistent with ANSI standards and with each other, will replace the older terminals as either traffic or operational considerations require.

The constraints are defined by dividing the terminals into categories, where all terminals in any particular category are compatible to the point of being able to be placed on a common multidrop circuit, but terminals in different categories cannot share a circuit. The basis for division includes physical characteristics of the terminals, compatibility of operating procedures, and administrative policies. The cost and administrative decisions required to make terminals in different categories compatible are considered elsewhere.

The categories are determined by considering the existing networks, then the impact of the categorization on achievement of an integrated network is appraised. Finally, a summary statement of the categories as constraints is presented.

A.2 SERVICE B

A.2.1 General

The Service B system is a common user low speed teletypewriter network used primarily for the transfer of the major share of flight planning information, but also serving a variety of other functional needs. The transmission of VFR and IFR flight plans acounts for the bulk of the traffic. Other types of messages involve safety, weather, notices, NOTAMS, emergency information and administrative matters. Table A-2 lists message categories by ICAO precedence with their handling requirements.

A.2.2 Service B Subnetworks

The network is composed of several subnetworks described in terms of the circuits in the subnets. The subnets and circuits are categorized below:

- Area B Subnetwork
    - Area B Circuits
    - Supplemental Circuits

Utility B Subnetwork

Air Carrier Circuits
Military Circuits

Center B Subnetwork

Center B Circuits

Computer B Subnetwork

Computer B Low Speed Circuits
Computer B High Speed Circuits

The most common circuit in Service B is a 75 bps (100 wpm) multipoint line connecting Model 28 teletypewriter terminals. Although the circuits have a common line protocol, they may serve different functional needs. It is on the basis of these differences that the above categories are formed. Each of the categories is briefly discussed below in order to form and justify categories of terminals to be used in constraining the design process.

A.2.3 Area B

The Area B subnetwork forms the backbone of the Service B system. It consists of approximately 36 multipoint send/receive (S/R) 75 bps circuits interconnected by a 750 bps high speed circuit and approximately 4 receive only (R/O) multipoint 75 bps circuits, similarly attached to the 750 bps high speed circuit, serving to relieve the heavy traffic load on the S/R circuits. The basic S/R circuits are called Area B circuits and the R/O circuits are called supplemental circuits. A functional diagram of the Area B subnet is shown in Figure A-1. A brief explanation of this diagram is given below.

An Area B circuit (1) is a half-duplex (every device hears all transmissions) 75 bps facility. The model 28 teletypewriter terminals (2) are five-level, 7.42 unit code

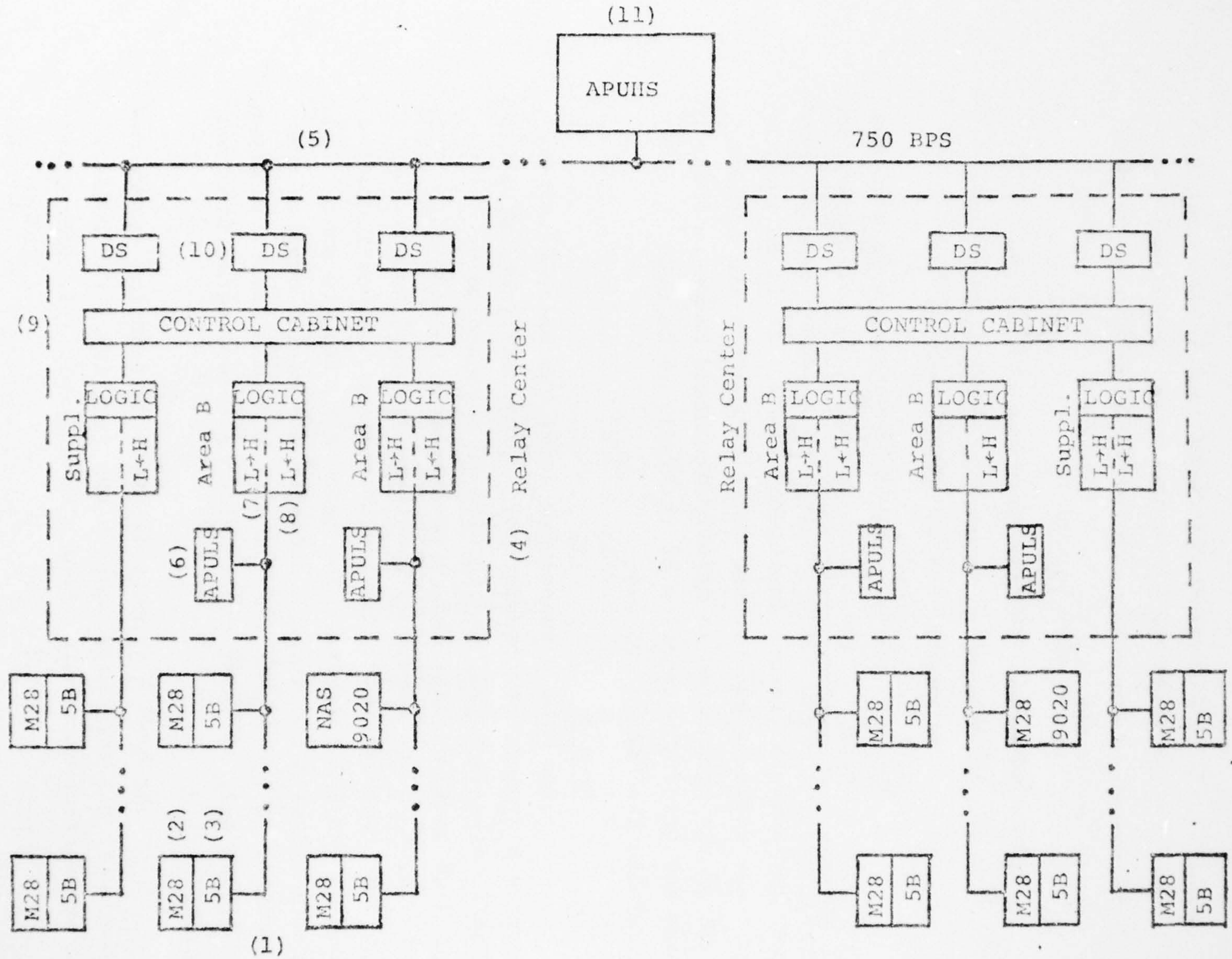


FIGURE A-1: AREA B FUNCTIONAL DIAGRAM

devices which operate at 75 bps, and are connected to the circuit through stuntboxes (3). The stuntbox is an electromechanical device that provides the control functions enabling polled operation and is distinguished from the keyboard and printer elements composing the "terminal".

The Area B circuits are terminated in a relay center (4) which houses the necessary equipment to transfer messages to and from the high speed interconnecting circuit (5). Connected to the Area B circuit is an electromechanical device called an Automatic Polling Unit - Low Speed (APULS) (6). The APULS provides the polling discipline for the circuit. Also connected to the circuit is a low speed reperforator and associated high-speed transmitter which is coupled to the reperforator through a paper tape loop and is used to transfer messages destined for terminals on other circuits to the high speed circuit (7). Similarly, there is a high speed reperforator and low speed transmitter for transfer of messages from the high speed circuit to the low speed circuit (8). A control cabinet (9) (for intracenter circuit transfers) and Bell System 202 data sets (10) for the high speed circuit complete the relay center equipment.

The operation of the circuit is as follows:

a. The APULS transmits a polling sequence consisting of seven characters as shown below:

$$\equiv \; < \; \downarrow \; A_1 \; A_2 \; \rightarrow \; \rightarrow$$

(Table A-1 explains these symbols and others used subsequently.)

Table A-1

Control Character Symbols and Meanings

Symbol	Meaning
≡	line feed
< or ←	carriage return
↓	letters shift
↑	figures shift
→ or Δ	space
b̸	blank
A_1, A_2, etc.	any alphabetic character
N_1, N_2, etc.	any numeral
A, B, etc.	the actual character shown
DD	numerals indicating day of the month
HH	numerals indicating hour of the day
MM	numerals indicating minutes past the hour
* (N) *	N repetitions of the character *

b. The first three characters of the polling sequence $(\equiv < \downarrow)$ referred to as a "condition code" place all the stunt boxes in a "select condition" permitting interpretation of the following characters as an address sequence.

c. The two alpha characters are an address sequence for the terminal being polled. The address sequence used to specify polling (two letters followed by two spaces) is called the transmitter start code (TSC). If the terminal has no message to send, it will simply remain idle. The APULS will time out after approximately two seconds and advance to poll the next terminal.

d. If the terminal polled has a message to send, its stunt box will recognize the TSC and transmission will commence after the

completion of the TSC. The terminals not polled, not having recognized a TSC, return to the non-select condition existing before the polling sequence.

e. The transmitted message format is as follows:

$< \; < \; \downarrow \; A_1 \; A_2 \; A_3 \; << \; \equiv \; \text{TEXT} \; \downarrow \; < \; < \; \equiv \; (7) \; \equiv \; N \; N \; N \; N$

The first three characters are again a condition code which places all stunt boxes in a "select condition". (Note that the first character of this condition code is the "<" rather than the "≡" used in the polling sequence condition code, as the reset function is not required here.

f. The three letter address code (usually called a "call directing code", or CDC) selects a particular terminal on the circuit for reception of the message. (Recall that all terminals on the circuit will hear this transmission.) If the message is to be transferred to the high speed circuit, the CDC is four letters, the first of which is an X that is used to start the reperforator.

g. After the three character CDC, a three character "alignment" code (< < ≡) is transmitted. This code resets the stunt boxes of all terminals to the non-select condition but leaves the printer of the called terminal enabled. In this way, an uncalled terminal is prevented from receiving a portion of the message accidentally should the message text contain a sequence of characters identical to its CDC. Following the alignment code, either another condition code,

CDC, and alignment code sequence, representing another addressee, or the message follows.

h. In general, Service B message text (non-computer B) complies with the following format:

1. Preamble:

   (a) Precedence sign (see Table A-2)

   (b) Address identifier of destination terminal.

   (c) Message 3-character sequential serial number.

   (d) Originating station identifier.

2. Address: (i.e., office or individual to which message is to be delivered). Omission indicates addressee is identical with teleprinter address identifier.

3. Text:

4. Signature:

   Transmitted one line below text includes:

   (a) Last name of originator.

   (b) Reference number or abbreviation of the originating office.

   (c) Date-time of origin.

Some deviations from this format are required in certain instances.

i. Selected terminals (and the reperforator, if selected) copy the message. At the end of the message a page feed sequence of seven line feeds and an "end of message", EOM, sequence of four N's are transmitted. This trailer sequence serves to disable all printers.

j. The APULS also recognizes an idle line, following a transmission of a message, and thereafter resumes its polling sequence.

TABLE A-2

CATEGORIES OF MESSAGES

ICAO Precedence Indicator	Types of Messages	Transmit Time	Delivery Instructions
1. "SS"	Message involving the safety of life and property. Restricted to emergency information.	Seize circuit (except Alaskan & Pacific and transmit immediately.	Immediate delivery to all addressees. Addressees required to acknowledge.
2. "DD"	Priority operational and circuit control messages.		Immediate delivery to all addressees.
"FF"	Flight movement and control messages directly relating to the safe and efficient operation of aircraft. Priority directive format administrative messages.	Transmit as soon as possible without interrupting scan.	Immediate delivery to all addressees on circuit. Notify circuit addressees for pickup or make telephone delivery during duty hours. When office closed, notify addressee chief or duty officer of message and subject, and deliver according to local instructions.
3. "GG"	TWEB Forecasts, nonurgent circuit control messages, flight cancellation and delay messages. Routing operational messages. Follow-up data relating to aircraft accident/incident reports.	Transmit as soon as possible without interruption to higher priority traffic.	Immediate delivery to all addressees.
"JJ"	All types not included above, such as NASCOM Reports, Routine directive format administrative messages	Transmit during the hours of 2100/0300 local time.	Immediate delivery to all addressees on circuit. Notify off-circuit addressees not later than 1030 local time on the next business day. Make delivery according to local instructions.

Flight Services, 7110.10B, 1 Jan. 1973, FAA

k. To transfer messages from the high speed circuit, the APULS includes the interface low speed transmitter on its polling list (with polling sequence ≡ < ↓ Q S Б ↓ ≡). The low speed transmitter responds analogous to an ordinary terminal.

Codes associated with the functions described are listed in Table A-3.

The transfer of messages over the high speed circuit begins with the low speed interface reperforator. After this reperforator has punched a paper tape of a message for transfer over the high speed circuit, the interface logic sets a message available indication. The Automatic Polling Unit, High Speed (APUHS) (11), polls each connecting high speed circuit in a manner analogous to the APULS except that interface circuits respond with a "message not available" transmission when they have no message rather than remaining idle. Thus, if the APUHS receives no response, it times out and initiates an alarm. The high speed circuit is a four-wire facility bridged to operate half-duplex so that every interface circuit can hear the transmissions on the high speed circuit of all other interface circuits. When a message is transmitted on the high speed circuit, the interface logic of the low speed circuit with the appropriate terminal recognizes the terminal's address and copies the message with the high-speed reperforator. The message is then available for transmission over the low speed circuit in the manner described above.

The supplemental circuits are used to off-load busy terminals on Area B circuits. Thus, messages transmitted on the high speed circuit to be transferred to a location served by a supplemental circuit are not copied by the Area B circuit interface high speed reperforator, but rather by the

TABLE A-3

SERVICE B ASYNCHRONOUS CHANNEL CONTROL CODES

1.	Polling sequence condition code	3 Characters	≡ < ↓
2.	Message transmission condition code	3 Characters	< < ↓
3.	Call Directing Code (CDC)	3-4 Characters	A_1 A_2 A_3 or XA_1 A_2 A_3
4.	Transmitter Start Code (TSC)	4 Characters	A_1 A_2 → →
5.	Alignment Code	3 Characters	< < ≡
	and		
	End of Line Code (EOL)	3 Characters	< < ≡
6.	End of Text Sequence (EOT)	4 Characters	↓ < < ≡
7.	End of Message Sequence (EOM)	4 Characters	NNNN

supplemental circuit interface high speed reperforator. The supplemental circuit low speed transmitter then forwards the message to the R/O terminal. The stunt boxes associated with the R/O terminals are programmed to accept messages in the same manner as the S/R terminals. Clearly, to be of use, a supplemental terminal cannot be on the same circuit as the terminal it supplements.

The following two categories of terminals are now defined:

Category A: Area B S/R terminals operating according to the procedures outlined above, which will be called P_1 procedures.

Category B: Supplemental R/O terminals operating consistent with P_1 procedures.

Before leaving this description of Area B, it should also be noted that the NAS 9020 computers also have drops on the Area B circuits. The computers also operate according to P_1 procedures (but with a polling sequence of $\equiv < \downarrow Z\ C\ A_1\ 5$).

A.2.3.1 Utility B

The Utility B subnet is used to transfer military and commercial carrier IFR flight plans to the center responsible for the area in which the flight originates. The circuits in the subnet are 75 bps (100 wpm) half-duplex facilities. They are intended to provide stations that have frequent daily insertions of IFR flight plans with a direct connection to the responsible NAS 9020 computer. The message format is that prescribed for machine entry of flight plans directly into the NAS 9020 computer. The circuits are terminated either in the NAS 9020 computer or at a terminal where an operator can easily

manually enter the flight plan in the computer. Thus, the function of the Utility B circuits is much narrower in scope than that of the Area B circuits. There is no connection of the Utility B circuits to the high speed circuit interconnecting Area B circuits. Some of the circuits are S/R and are polled by APULS units, while others are R/O at the ARTCC. Some of the latter type have been terminated in the NAS 9020 computer.

The Utility B circuits are primarily intended for military air base operations offices (BASOPs) and commercial carrier dispatch offices. However, there are also approximately 33 high-activity Flight Service Stations (FSS) that are served by these circuits in order to have additional capability and a secondary means of distributing data. In addition, two Canadian centers are served by Utility B circuits. In general, air carrier terminals are on multipoint circuits at major airports terminated in R/O drops at the responsible ARTCC; consequently they do not share circuits with military terminals. All Utility B circuits are operated consistent with the P_1 procedures outlined above for Area B circuits. The following two categories of terminals are now defined:

Category C: S/R terminals located at BASOPs or FSSs, dedicated to insertion of flight plans in machine format and operating according to P_1 procedures.

Category D: S/R terminals located at air carrier dispatch offices, dedicated to insertion of flight plans in machine format, and operating according to P_1 procedures.

It should be noted that recent administrative decisions have been oriented towards expanding Category C to allow additional air carrier facilities to be served by Utility B circuits.

However, the extent to which these decisions have resulted in new drops on Utility B is not readily known.

A.2.3.2 Center B

The Center B subnet is composed of five (100 wpm) circuits terminated in the DS 714 AFTN switch at NATCOM in Kansas City. The switch operates each circuit according to the P_1 procedures and provides for their interconnection. All ARTCCs have a S/R drop on one of the circuits. In addition, the SCC-ARO (Systems Command Center - Airport Reservations Office) in Washington, D.C. has a drop and the record center at Martinsburg, West Virginia has a drop.

The Center B network is primarily used for the exchange of flight movement and control messages normally related to IFR flights between the areas controlled by the conterminous ARTCCs and the SCC-ARO. The following category is now defined:

Category E: S/R terminals located in ARTCCs, the SCC-ARO, and the record center, primarily used for the exchange of flight movement and control messages, and operating according to P_1 procedures.

A.2.3.3 Computer B

The Computer B network is composed of low speed and medium speed circuits interconnecting all the NAS 9020 computers on a point-to-point basis. The network is intended only for computer-computer communications, is not part of the common user message transfer system, and is not included in the scope of this study.

A.3 AFTN

The Aeronautical Fixed Telecommunications Network (AFTN) is a world wide teletypewriter communications system intended primarily for the exchange of messages concerning the safety of air navigation and regular, efficient, and economical operation of international air services. The AFTN provides communications service for international aircraft movements, administrative messages, and meteorological data between the U.S. and other International Civil Aviation Organization (ICAO) nations. Specifically the categories of messages handled by the AFTN are:

a. distress messages and distress traffic (SS)
b. urgency messages (SS)
c. flight safety messages (FF to GG)
d. meteorological messages (GG to JJ)
e. flight regularity messages (GG to JJ)
f. aeronautical administrative messages (JJ)
g. NOTAM - Class I distribution (GG to JJ)
h. reservation messages (KK)
i. general aircraft operating agency messages (LL)
j. service messages (as appropriate)

This listing includes, in parentheses, the level of precedence range in which each category of message is handled. Table A-4 defines the AFTN precedence levels.

The present portion of AFTN for which FAA has responsibilities is divided into two major areas - the North Atlantic and Caribbean Area, and the Alaskan and Pacific Area. The Alaskan and Pacific Area is served by multiple switching centers at Anchorage and Honolulu. These centers operate in a full automatic mode.

TABLE A-4

AFTN PRECEDENCE LEVELS

Precedence Designator	Type Messages
1. SS	Emergency messages affecting safety of life and property.
2. DD	Message requiring special priority handling.
3. FF	Messages concerning control and movement of traffic. Flight safety messages.
4. GG	Flight regularity messages and meteorological forecasts.
5. JJ	Administrative messages, meteorological observations, and flight regularity messages.
and	
KK	Reservation messages.
6. LL	Company and operating agency messages.

In 1970, the FAA replaced the manual switching centers associated with the North Atlantic and Caribbean Area with an automated central distribution center at Kansas City, Missouri. Its function is the relay of international meteorological and aeronautical traffic originally relayed at each of four locations: New York, Miami, San Juan, and Balboa. These four locations have now become hubs which feed the Kansas City center. The Honolulu center has been converted to the same type of hubbed operation as Kansas City.

The most common terminal in the AFTN is the Model 28 teletypewriter. There is a large number of point-to-point circuits and multipoint circuits. The message format is defined by ICAO standards, and is different from that used in Service B. The format is described in detail in ICAO document number 7946-AN/868/4, Amendment No. 7 (25/5/73), Manual of Teletypewriter Operating Practices. The basic format has five major divisions: heading, address, origin, text, and ending. These are described briefly below:

a. Heading

$$\underbrace{Z\ C\ Z\ C}_{1}\ \underbrace{\rightarrow A_1\ A_2\ A_3}_{2}\ \underbrace{\uparrow N_1\ N_2\ N_3}_{3}\ \underbrace{\rightarrow \rightarrow \rightarrow \rightarrow \rightarrow}_{4}\ \underbrace{\downarrow < < \equiv}_{5}$$

1 - Start of message code

2 - Transmitting station identifier

3 - Message sequence number

4 - Tear space (with manual switching systems only)

5 - Alignment code

b. Address

$$\underbrace{A_1\ A_2}_{1} \rightarrow \underbrace{A_3\ A_4\ A_5\ A_6}_{2}\ \underbrace{A_7\ A_8}_{3}\ \underbrace{A_9\ A_{10}}_{4}\ \underbrace{<\ <\ \equiv}_{5}$$

1 - Precedence designator (see Table A-4)

2 - Address location

3 - Address organizational indicator

4 - Optional extension of address organizational indicator

5 - Alignment code

c. Origin

$$\underbrace{\uparrow D\ D\ H\ H\ M\ M \downarrow \rightarrow}_{1}\ \underbrace{A_1\ A_2\ A_3\ A_4}_{2}\ \underbrace{A_5\ A_6}_{3}\ \underbrace{A_7\ A_8}_{4}\ \underbrace{<\ <\ \equiv}_{5}$$

1 - Date and time of origin

2 - Originating location

3 - Originating organization indicator

4 - Optional extension of originating organization indicator

5 - Alignment code

d. Text

e. Ending

$$\underbrace{\downarrow < <}_{1}\;\underbrace{\equiv \equiv \equiv \equiv \equiv \equiv \equiv \equiv \text{N N N N}}_{2}\;\underbrace{\downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow}_{3}$$

1 - End of text indicator

2 - End of message indicator

3 - Tear space (with manual switching systems only)

There is no ICAO standard describing polling procedure to be used on the AFTN system. However, in most of the AFTN operated by the United States, the polling procedure is a modified version of the Bell System 83B3 Teletypewriter Selective Call System, as described below.

a. The switching center transmits a two character (A_1 A_2) TSC for the station being polled, and then initiates a time-out.

b. If the polled station does not have a message to be transmitted, it transmits the character "V", and after receiving this character, the switching center advances its poll to the next station.

c. If the polled station has a message to be transmitted, it first transmits an "End of Address" sequence (< ≡ ↓) to block all other terminals from detecting their address in the normal

message traffic, and then it transmits the message.

d. When the switching center receives the "End of Message" sequence (N N N N), it resumes polling.

e. If the switching center receives no response during its time-out interval, it transmits the "End of Message" sequence which resets all terminals and causes an alarm; then it resumes polling.

f. If the switching center has a message for delivery to a terminal, it transmits a three character CDC for the terminal (A_1 A_2 ↓) and then waits for receipt of a "V" from the terminal signifying recognition of the CDC.

g. Upon receipt of the "V", the switching center transmits an "End of Address" sequence (< ≡ ↓) followed by the message.

The above procedure, with its incorporation of an answer-back when a terminal has no message and during switching center to terminal message delivery, is substantially different from the P_1 procedures described for Service B. Furthermore, since all messages in AFTN must be journaled by the switching center, direct intracircuit terminal to terminal message transfers are not permitted, even though the circuit is half duplex. This AFTN procedure will be called P_2. Since all AFTN terminals adhere to a common message format and have similar functions, it may appear appropriate to place them all in one category, assuming terminals on point-to-point circuits could easily be modified to operate according to P_2 procedures. However, the terminals are located in distant geographic regions, to the point where multidrop lines of terminals in different regions would be inappropriate. It is on this basis that

categorization is made.

The geographic regions served by AFTN circuits are the conterminous U. S. (CONUS), Alaska, Pacific, and Caribbean regions. In addition, there is an interface with the international aeronautical telecommunications network. Each of these regions is briefly described below in order to justify the categories developed.

A.3.1 CONUS

Within the CONUS, there exist AFTN terminals on seventeen point-to-point circuits and on ten multi-point circuits. Each multipoint circuit connects several airlines at a common airport. Circuits are terminated in the DS714 switch at Kansas City. Multiplexers are currently present in New York, Miami and San Francisco. This arrangement leads to defining the following two categories of terminals.

Category F: CONUS AFTN terminals not serving airlines bunched at airports.

Category G: CONUS AFTN terminals serving airlines bunched at airports.

A.3.2 Alaska

The terminals in Alaska are used for both Service B and AFTN traffic, but operate in the AFTN format. All terminals are connected to a Philips ES-3 switch located in Anchorage, which provides fully automatic teletypewriter switching with manual (push button) switching capability used when circuit conditions preclude fully automatic operation. All lines operate at speeds of 100 WPM. Control of transmission from and to terminals on the various circuits as well as the fully automatic

switching of messages is performed by the switch. Only emergency, non-routing functions or error conditions are called to an operator's attention.

The Anchorage ES-3 System provides communications switching capabilities for the Alaskan region IFSS's as well as a switching interface between AFTN and Service B. It represents an integrated Service B/AFTN switching system in Alaska and in a sense, is a precursor to the NADIN concept.

In general, traffic originates and is transmitted as follows:

- Intra-Alaska (between FSS's, FAA offices, etc...)
- To/From San Franscisco
- To/From Tokyo
- To/From Honolulu IATSC

Reports of Fixed Services Activities and peak hour message forms have provided traffic data which were supplemented by site surveys and teletype roll analysis

• Total annual (1973) traffic	3×10^6 msgs. 200×10^6 words
• Average weekly traffic	57×10^3 msgs. 3×10^6 words
• Average daily traffic	8×10^3 msgs. 528×10^3 words
• Busy hour traffic	435 msgs.
• Percentage of total traffic sent to CONUS	6%
• Percentage of total traffic received from CONUS for Alaskan distribution	12%

These messages are transmitted on the following categories of circuits: four multipoint circuits serving terminals in outlying areas, a multipoint circuit serving airlines in Anchorage, a multipoint circuit shared by Canadian

authorities and the United States military, and approximately 21 point-to-point circuits in Anchorage. This arrangement leads to defining the following categories of terminals:

Category H: Alaska outlying terminals.
Category I: Anchorage non-airline terminals.
Category J: Anchorage airline terminals.
Category K: Canada and U.S. military terminals.

A.3.3 Pacific

The AFTN terminals in the Pacific are connected to the switching center at Honolulu, a Western Union Plan 59A.

A.3.3.1 Hawaii

Honolulu has approximately 16 local point-to-point circuits; two local multipoint circuits connecting airlines; circuits to Pago Pago, Midway, Kwajalein, Guam, Anchorage, and Kansas City; and international circuits to Manila, Fiji, and Japan.

A total of 34 circuits presently handles AFTN communication requirements. A portion of the traffic is non-AFTN as weather data is sent over these circuits for redistribution to other stations connected to the center. Circuits operate at speeds of 60, 67 and 100 WPM.

A great variety of transmission links are used to interconnect the area stations with the switching centers, e.g., sub-voice grade land lines, satellite links, undersea cables, radio links.

Undersea cables link the IATSC with Japan, Guam, Manila, Wake Island, Fiji and Midway Islands. Satellite channels are used between the center and Japan, NMC Suitland, San Francisco and Anchorage. Land line circuits provide

transmission capabilities for intra-island communications. Two of the circuits are multipoint full duplex while others are half duplex or simplex. Several land line circuits are operated in a simplex broadcast mode where the traffic from the center is sent to all stations on the particular circuit.

Transmission with a station on a multipoint circuit under the switching jurisdiction of Honolulu is accomplished by means of the following select code: two letter-shift characters, "W", the station alphabetical identifier "A, B, C, etc.", one carriage return and one line feed (↓↓WA<≡). These functions are automatically perforated on the outgoing tape preceding the start of message. The two letter-shift characters, "W", and the correspondent's identifier turn on the receiving equipment. The carriage return indicates the end of the select mode and locks other equipment on the circuit. Line feeds act only as a prevention against "SOM" overlining when more than one terminal is selected. The EOM unlocks previously locked out terminals. Group codes are used for simultaneous transmissions to all terminals on the circuit. Devices on multipoint circuits are equipped with "idle start" and "transfer lockout". The idle start permits only one sender to transmit at a time. The transfer lockout prevents terminals from receiving each other's transmissions. Incoming messages must be in proper ICAO format and contain the SOM, a three letter indicator, channel number , text and a valid EOM.

The Honolulu IATSC is the extension of AFTN in the Pacific area. Its geographical location as well as its switching capabilities have placed it as the Pacific hub responsible for the orderly exchange of air services messages in that area. As shown below a large portion of the traffic handled by the Honolulu IATSC is destined to intra-Pacific locations. A quarter of the total data communication load is received from or relayed to the CONUS.

Reports of Fixed Services Activities and peak hour message forms collected at the Honolulu IATSC along with on-site surveys, have revealed the following traffic information.

• Total annual (1973) combined AFTN/MET traffic	6×10^6 msgs. 523×10^6 words
• Average weekly traffic	155×10^3 msgs. 10×10^6 words
• Average daily traffic	22×10^3 msgs. 1.5×10^6 words
• AFTN/MET busy hour traffic	768 msgs.
• AFTN busy hour traffic	600 msgs.
• Average message length	300 char.
• Percentage of total traffic send to CONUS for redistribution	17%
• Percentage of total traffic received from CONUS for Pacific distribution	8%

A.3.3.2 Other Pacific Switches

The switches at Guam, Wake Island, and Pago Pago appear to have a minimal AFTN role, serving primarily as relay points for the Honolulu circuits. There is a multipoint circuit connecting airlines at Guam. This arrangement leads to defining the following categories:

Category L: Hawaiian Island non-airline terminals.

Category M: Honolulu airline terminals.

Category N: Pacific outlying terminals.

A.3.4 Caribbean

The Caribbean AFTN terminals are on circuits hubbed at a multiplexer in San Juan. There are five local point-to-point circuits, plus a point-to-point circuit to Guantanamo Bay, and two local multipoint circuits connecting airlines. This leads to the following two categories being defined:

Category O: Caribbean government terminals.

Category P: Caribbean non-government terminals.

A.3.5 International

The AFTN network is international in scope. The portion operated by the United States interconnects with portions operated by other nations at many points. The interconnecting circuits are not considered available for optimization as part of NADIN. These circuits will, however, impact the traffic load to be handled by switches within NADIN. They include circuits to Balboa, Bermuda, Montreal, Lisbon, Tokyo, Manila, Fiji, and a series of circuits hubbed at San Juan in the Caribbean.

A.4 NADIN

A basic objective for NADIN is the integration of the existing Service B and AFTN facilities into a single common user network. However, the discussion of the existing networks presented above outlined fifteen categories of terminals, each category in some sense being distinct and incompatible with other categories. A fundamental question is the impact of such different categories on the achievement of an integrated network. In this section, a basic structure for NADIN is outlined and is then related to the above categories, shown to be consistent with the guiding principle outlined in the first section, and used to form new categories of terminals for investigating alternative network architectures for NADIN.

In terms of topology, NADIN may be viewed as composed of the four AFTN geographic regions; each region deserving consideration in its own right, but also having to be interconnected with the others and having to be locally consistent with the global objectives for an integrated common user network. As a message transfer system, NADIN requires at

least one switching center to perform the transfer of messages between circuits and to fulfill the journaling requirements for AFTN messages. For reliability, site redundancy should be present, suggesting at least two such centers. Beyond this minimal requirement, the need for other centers is to be a part of this study. Thus, each region may be serviced by none, one, two, or more switching centers, so long as there are at least two centers in a reliable configuration for the total NADIN. Some preliminary considerations of NADIN as a total system make the options considerably more precise. The categories for use in the design process are developed on the basis of the regional considerations.

A.4.1 Preliminary Considerations

For conceptual purposes, consider the design problem in its most basic form: a set of terminal sites widely dispersed over the four regions defined above, with a basic requirement for each terminal to be able to communicate with each other terminal. Traffic requirements will restrict the number of terminals that can be placed on a single multidrop circuit. The dispersion of terminals, coupled with this restriction, makes it economically attractive to place concentration facilities at locations where they can be used to reduce the cost of connecting the circuits to switching centers. In this context, switching centers may also be viewed as concentration facilities for connection of terminals to other switching centers. Thus, the concentration facilities may be any of the following:

- multiplexer,
- concentrator,
- concentrator with switching, but without journaling,
- switching center, complete with journaling.

A functional description of each of these devices is given in a later section.

For reliability, each of the facilities of the first three types should be able to communicate with at least two switching centers, with one communication path over a dedicated leased line and the other possibly being a dial-up backup line. The switching centers should be able to assume the load of any failed centers.

Because of the geographic immensity of the CONUS and the large number of terminals and traffic in this region, at least two switching centers are required. In Alaska and the Pacific, there are considerably fewer terminals, correspondingly less traffic, and geographic considerations that make at most one switching center feasible for Alaska at Anchorage and one switching center feasible for the Pacific at Honolulu. It may be more attractive to use one of the other concentration alternatives at these locations. In the Caribbean, the small number of terminals and traffic can only justify either a multiplexer or a concentrator. The functional alternatives for the overall network are displayed in Figure A-2. In this arrangement, integration will be achieved through the capability of the switching centers and concentrators to perform code conversion and to carry out the different line procedures necessary to operate circuits with different categories of terminals.

The design task for the overall network can be divided into two parts; design of the subnet within each region and the interconnection of the regions. These two parts are not independent; however, it is appropriate to consider some of the constraints on terminal connection to concentration facilities on a regional basis. These constraints

are developed below in the form of the categories described above. However, before proceeding to this development, it should be noted that a new category of terminal will be present in NADIN that is not present in the existing systems. This is the category of medium speed terminals using the seven level ITA #5 code and operating consistently with ANSI standard procedures (which will be called P_3 procedures). These terminals will replace Model 28 teletypewriter terminals as either traffic or operation considerations warrant and can be interconnected whether serving primarily AFTN or Service B users. Thus, they are the basic terminals for the integrated network, and are the basis for defining the following category:

Category Q: Seven level ITA #5 medium speed terminals operating with P_3 procedures.

A.4.2 CONUS

Within the CONUS, circuits from terminals will be connected to either multiplexers, concentrators, or concentrators with switching. The generic term, concentration facility (CF), will be used to describe such devices. The existing categories of terminals to be connected to CFs are A, B, C, D, E, F, and G. In addition, terminals in Category Q are to be included. Furthermore, the NAS 9020 computers should be on circuits connected to CFs in order that terminals may have access to the computers. The existing categories have evolved due to a number of different reasons. However, in considering the design of NADIN, it is appropriate to consider the requirements in terms of locations which must be provided service using existing equipment, where practical, and not in terms of simply serving all existing terminals. Thus, categories A, B, and E are operationally compatible, and should be considered as defining a single category of locations to be served by either existing terminals or new terminals (Category Q). This

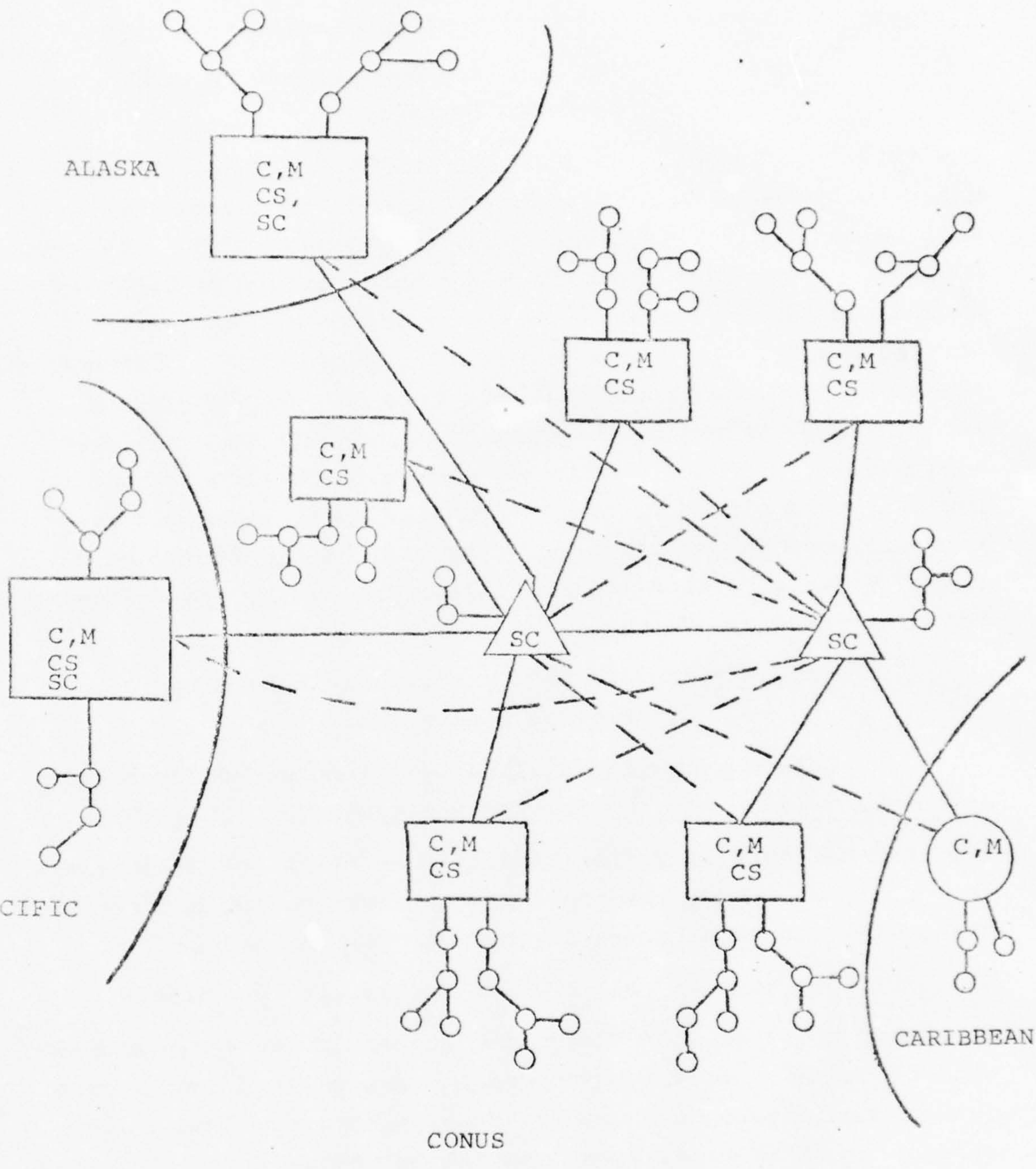


FIGURE A-2. FUNCTIONAL ALTERNATIVES FOR NADIN

LEGEND

SC - Switch Center
CS - Concentrator with Switch
C - Concentrator
M - Multiplexer

category of locations is formally defined below:

Category 1: All Area B, Supplemental B, and Center B locations.

The existing Categories C (BASOPs) and D (Airlines) are to be extended in NADIN to permit general access to the network as well as to simply file flight plans to the NAS 9020 computers. However, circuits serving BASOPs are to have only BASOPs connected, for privacy reasons. The locations of terminals serving airlines in Category D overlap with those in Category G. Although operating procedures for these two categories are incompatible, change to a compatible procedure is considered appropriate, and thus, these two categories will be merged together as a single category. Because these terminals are naturally bunched at airports, they will be considered as a separate category from the FAA terminals. Thus, the following two categories are defined:

Category 2: All BASOPs currently served by Service B circuits.

Category 3: All airline locations currently served by Service B circuits.

The last category to be included is that of the AFTN terminals in the CONUS. These terminals are considered distinct from all the above, and thus define another category as below:

Category 4: All AFTN terminals with the CONUS.

It should be noted that Category Q terminals (medium speed ANSI consistent) will be drawn from categories one and four as the design considerations warrant. Thus, within the CONUS, four categories of terminal locations are defined. Figure A-3 shows the functional relation of these categories to the NADIN structure within the CONUS.

A.4.3 Alaska

The existing Alaskan terminals have been placed in four categories: H, I, J, and K. The last category, K, consists of terminals on a circuit shared by the Canadian and U.S. military establishments. This circuit is not to be considered in the scope of this study. Of the other three categories, all terminals are compatible. However, Category H, containing the outlying terminals, is the only category of interest for the topological design. Category J contains the airline multipoint terminals which are all located at the Anchorage airport and Category I contains terminals served by point-to-point circuits in the Anchorage vicinity. These terminals (Category I) may be placed on multipoint circuits if warranted by I/O port costs or multiplexing channel costs, but will not significantly affect the topological design. Thus, these three categories will remain fixed, and simply relabeled as:

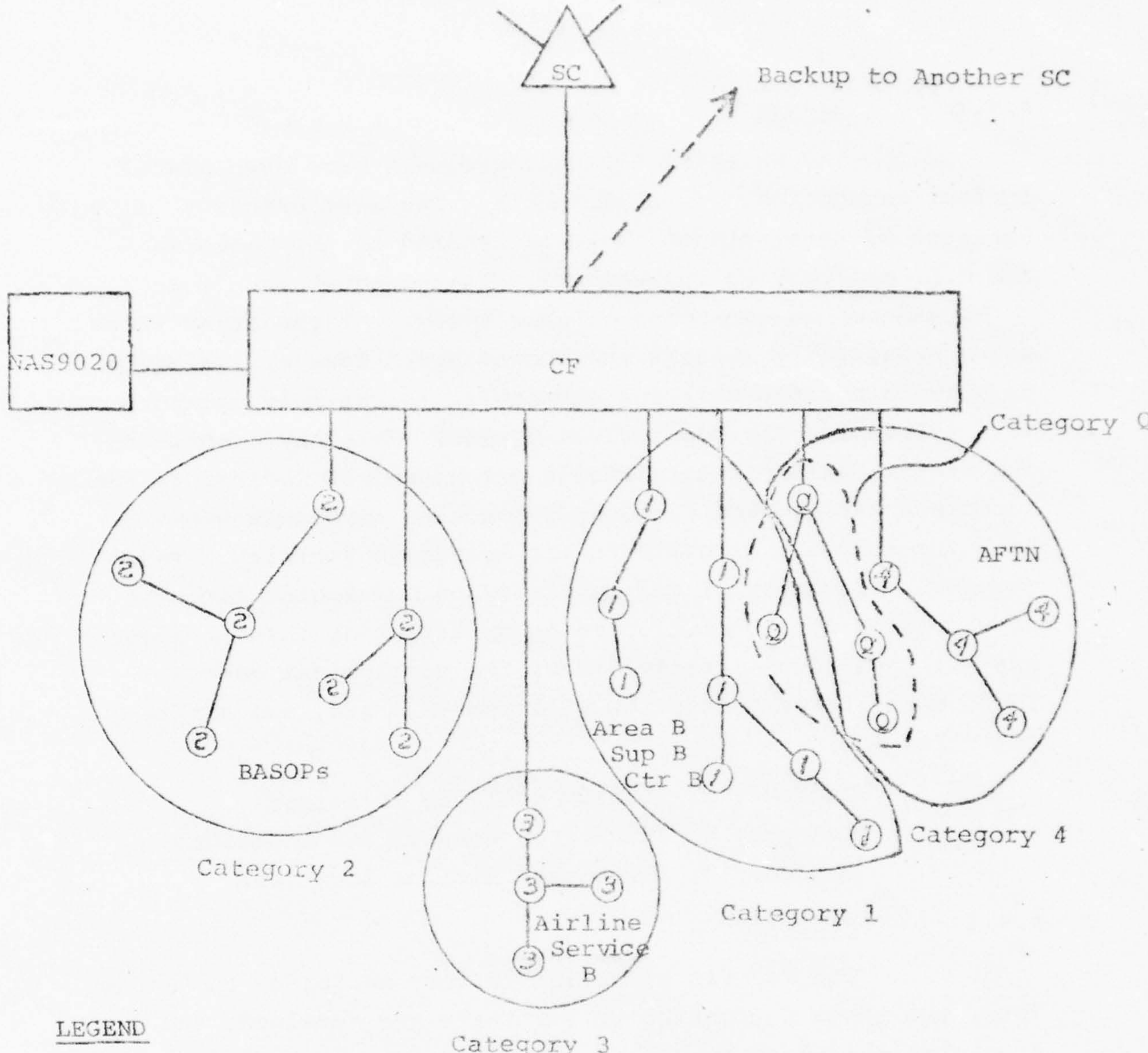
Category 5: Alaska outlying locations.
Category 6: Anchorage non-airline locations
Category 7: Anchorage airline locations.

A.4.4 Pacific

The Pacific situation is very analogous to Alaska. Thus, the three categories of terminals are retained, and simply relabeled as follows:

Category 8: Hawaiian Island non-airline locations.
Category 9: Honolulu airline locations.
Category 10: Pacific outlying locations.

Only the last category is of interest in the topological design.



LEGEND

SC - Switch Center

CF - Concentrator Facility

FIGURE A-3 FUNCTIONAL DIAGRAM OF NADIN CONTERMINOUS U.S. DESIGN

A.4.5 Caribbean

The Caribbean situation is very simple. There is only one terminal location, outside of San Juan, the Guantanamo Bay location. All other terminals are either on point-to-point circuits in San Juan or are on multipoint circuits serving the airlines at San Juan. Thus, the following two categories of terminal locations are defined, based on the existing system:

Category 11: Caribbean non-airline locations.

Category 12: Caribbean airline locations.

A.5 SUMMARY

NADIN is to provide an integrated telecommunications service to locations distributed in four major regions. In order to use existing equipment within each region, twelve categories of terminals have been defined that permit design based on existing facilities and operational restrictions. For locations requiring terminals other than those currently available, a medium speed, ANSI consistent terminal will be used. The twelve basic categories are summarized below:

- CONUS

  1. All Area B, Supplemental B, and Center B locations.
  2. All BASOPs currently served by Service B circuits.
  3. All airline locations currently served by Service B circuits.
  4. All AFTN terminals.

- Alaska

  5. Alaska outlying locations.
  6. Anchorage non-airline locations.
  7. Anchorage airline locations.

- Pacific

    8. Hawaiian Island non-airline locations.
    9. Honolulu airline locations.
    10. Pacific outlying locations.

- Caribbean

    11. Caribbean non-airline locations.
    12. Caribbean airline locations.

A listing of all locations in these categories is contained in Appendix H.

APPENDIX B

TOPOLOGICAL CONSTRAINTS

B.1 INTRODUCTION

As part of the NADIN design process, various topologies of circuits interconnecting terminals, concentration facilities (CFs) and switching centers (SCs) have been considered. There are many constraints on the topologies determined from traffic, performance, and reliability considerations. However, there are many practical considerations on the feasibility of obtaining circuits that also lead to constraints on the topologies. There are also practical considerations that simplify the topological design process. In this section, these various practical considerations and their impact on the NADIN topology design process are discussed.

B.2 LOCAL CIRCUITS

There are several situations in which terminals are located in immediate proximity to one another. These situations are easily divided into two categories: airline terminals at airports and terminals collocated with a CF. The circuit layout for such terminals is primarily dictated by local cost considerations and the cost of connecting circuits to a CF. The two categories are discussed below.

B.2.1 Airline Terminals at Airports

In the existing AFTN and Service B networks, there are more than 24 multipoint circuits serving airlines at 14 locations. For purposes of considering topological alternatives for NADIN, the terminals may be considered as a single location requiring a number of circuit terminations based on their exist-

ing configurations and projected traffic loads. Thus, in the NADIN design process, these terminals are replaced by single nodes on a per circuit basis. The listing in Appendix H are based on such consolidated nodes.

B.2.2 Terminals Colocated with a Concentrator Facility

In the existing AFTN and Service B networks, there are several locations at which terminals in the immediate vicinity of a CF have been conveniently connected to the CF on a point-to-point basis. These terminals could be placed on a multidrop circuit, but there is little topological impact by so doing. However, there would be an impact on the number of I/O ports used at a CF and, if the CF is a multiplexer, there would be an impact on the number of channels which must be derived. The impact of these alternatives is best appraised in terms of particular situations, as they depend on availability of ports, local cost factors, and equipment characteristics. However, for the purposes of this study, it is appropriate to simply consider all terminals in the same category at a common location near a CF eligible for placement on a local multipoint circuit, subject to the usual performance and traffic constraints.

B.3 INTRAREGION CONSTRAINTS

In order to determine topological constraints on practical considerations of obtaining circuits, it is appropriate to view NADIN as composed of four distinct geographic regions: Conterminous U. S. (CONUS), Alaska, Pacific, and Caribbean. Within each of these regions, there are practical considerations affecting the availability of circuits. These considerations are discussed below on a regional basis. In the next section, the acquisition of circuits interconnecting the regions is considered.

B.3.1 CONUS

Within the CONUS, circuits connecting any two points are usually obtained with little difficulty. Although no direct path may exist between the points, the tariffs are generally based on point-to-point distances derived from the customer's topological design, not on the distance of the physical layout of the channels as provided by the telephone company. However, there are practical considerations relative to the FAA that may constrain acceptable topologies.

The FAA has divided the CONUS into 20 regions of air traffic control (ATC) responsibility, as shown in Figure B-1. In each region there is an Air Route Traffic Control Center (ARTCC) responsible for the ATC functions in its region. The ARTCC is a major FAA installation; it usually houses the centralized facilities and personnel responsible for general system maintenance within its area. Furthermore, the ARTCC also houses the NAS 9020 computer to which all flight plans of flights originating in its region are to be directed. Thus, the ARTCC's are considered to be prime candidate sites for location of concentration facilities. Furthermore, because the regions correspond to areas of operational responsibility and because most traffic from a Flight Service Station (FSS) will be directed to the ARTCC in its region, it is considered attractive for circuits to be constrained on a regional basis. That is, all terminals in a region are to be connected to circuits entirely contained in the region (provided there is a CF in the region). This constraint is administrative in nature; it is to be considered as a design option for comparison to the unconstrained case, where cost differences and other factors will determine the final decision. The following statement is a formal specification of the constraints for this option, which will be called the ARTCC constraint option.

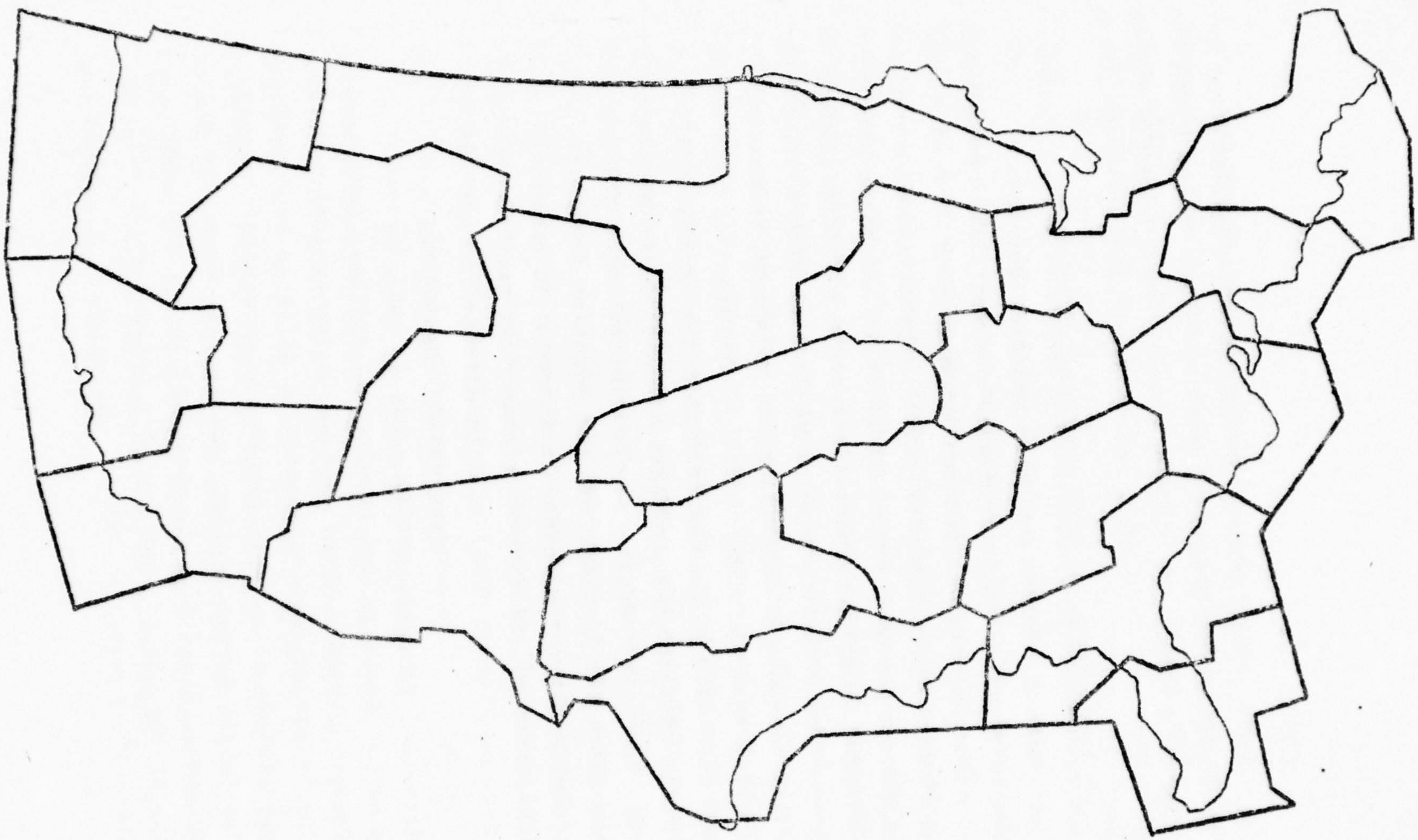


FIGURE B-1: AIR TRAFFIC CONTROL REGIONS

ARTCC Constraint Option

1. Every ARTCC is to have a concentration facility of some form.

2. All terminals in the region of responsibility of an ARTCC are to be connected to the CF at the ARTCC.

This option differs from the unconstrained case in both cost and traffic characteristics for the high level side of the network. These differences are appraised elsewhere. The locations subject to this constraint (Category 1) are listed in Appendix H on a regional basis.

B.3.2 Alaska

The immense size of Alaska, coupled with its sparse population and difficult terrain, places severe physical constraints on the interconnection of locations in the remote regions. However, the structure of the tariff for Alaska appears to be based on point-to-point distances derived from the customer's topological design, and not the physical routing of the circuits. Thus, the design process can proceed under the assumption that topological optimization is appropriate.

B.3.3 Pacific

The locations to be served by NADIN in the Pacific can be divided into two groups: those in the Hawaiian Islands and those in the outlying islands. The interconnection of points in the Hawaiian Islands is governed by local facilities and tariffs and is not of topological significance. The interconnection of points in the outlying islands is considerably constrained by the presence of existing facilities. The options available are listed below.

Guam

Cable to Wake Island

Radio to Wake Island

Kwajalein

Radio to Honolulu

Pago Pago

Radio to Honolulu

Radio to Fiji, cable from Fiji to Honolulu

Wake Island

Cable to Honolulu

Radio to Honolulu

B.3.4 Caribbean

The Caribbean is a particularly simple region for topological consideration. All but one of the locations of interest are in the immediate vicinity of San Juan, and consequently governed by local tariffs. These are not of topological significance. The remaining point, Guantanamo Bay, is constrained to a radio channel to San Juan. It should be noted that there are several international points in the Caribbean region which could be of topological interest. However, the topology of circuits connecting these points is not within the scope of this study.

B.4 INTERREGION CONSTRAINTS

The four regions of NADIN described above are geographically disjoint. The options available for the interconnection of these regions are determined by the presence of existing communication facilities. The options are described below.

Pacific-Alaska

Cable between Honolulu and Anchorage
Satellite between Honolulu and Anchorage

Pacific-CONUS

Cable between Honolulu and San Francisco
Cable between Honolulu and Los Angeles
Satellite between Honolulu and San Francisco

Alaska-CONUS

LOS microwave combined with cable from Anchorage to Seattle
Satellite between Anchorage and Seattle
LOS microwave between Anchorage and Montana

CONUS-Caribbean

Cable between Miami and San Juan

Cable and microwave facilities are to be preferred over satellites where economics permit due to the propagation delay in satellite systems (about 500 ms in a roundtrip).

APPENDIX C

TRAFFIC CONSIDERATIONS

C.1 INTRODUCTION

In order to design a cost-effective integrated network, appropriate traffic information describing the expected load for the network is required. However, it should be emphasized that proper network design is not based directly on detailed information of traffic flows at a message-by-message level. Any network designed on such a basis would never be able to survive the uncertainties expected in actual traffic flow in the real world of a dynamic network. Thus, in the NADIN design process, the traffic projections on a per station basis are used to establish the equipment and circuit requirements, and the resulting designs are carefully appraised for sensitivity to traffic variations and growth.

An appropriate traffic portrait for use in designing networks such as NADIN includes considerations of message length distribution, distribution of message arrivals at terminals, the rates at which messages arrive at the terminals, and the source-destination characteristics of the messages. It is often both impossible and inappropriate to determine and use these traffic characteristics in detail. As noted above, the network design should be insensitive with respect to changes in these characteristics, which will occur as the system evolves. However, it is necessary to formulate a reasonable portrait of the traffic characteristics in order to determine the necessary capacity of network components. In the sections which follow, such a portrait is derived.

C.2 MESSAGE LENGTH DISTRIBUTIONS

Terminals in the NADIN are expected to handle several different categories of messages, including all those currently handled by Service B and AFTN terminals, and possibly some new categories.

The message length distributions for the two different existing systems are different, due to differences in both format and content. However, current administrative policies are directed at making the basic message formats consistent. Furthermore, although initially the existing terminals will serve primarily their present roles, the evolving integration of the network will lead to terminals serving more general functions. With these considerations in mind and with an objective of developing a suitably general portrait, it appears that a common message length distribution for all terminals is appropriate. To develop this distribution, consideration is first given to the existing networks, and then to the integrated network.

C.2.1 Service B

The MITRE Corporation has described Service B traffic in two reports, MTR 4158 and MTR 1673. In MTR 4158 report, the traffic was characterized with contingency tables of message type categories and origin-destination categories. MTR 1673 concluded that message lengths within each category were consistent (few percent variation). The average lengths by category are given in Table 2.6 of MTR 1673 (Table C-1 here). Furthermore, the frequency distribution of the categories was consistent, as shown in Table 3.10 (Table C-2 here). However, the frequency distribution of the origin-destination categories was found to be invalid, and it is precisely this information which is needed to link the tables together to produce a message length distribution. In order

TABLE 2-6

TOTAL SAMPLE MESSAGE LENGTHS

MESSAGE TYPE CATEGORY NUMBER	STATION-COMPUTER MESSAGES (IFR ONLY)	STATION-STATION MESSAGES	
		IFR	VFR
1	130	83	75
2	70	40	40
3	70	165	135
4	50	50	50
5	50	65	65
6	38	28	28
7	90	50	50
8	60	75	75

FOOTNOTE: [1]Includes both printed and non-printed characters of the message.

TABLE C-1: MEAN MESSAGE LENGTHS FROM TOTAL SAMPLE

TABLE 3-10

DATA FOR χ^2 TEST OF TOTAL SAMPLE

MESSAGE TYPE CATEGORY NUMBER	TOTAL SAMPLE[3]. (o_i)	FREQ. DIST. USED IN[2]. MTR-4158	ADJUSTED[1]. FREQ. DIST. MTR-4158 (e_i)
1	629	29,711	781
2	110	3,978	104
3	87	3,534	93
4	60	2,623	69
5	93	1,223	32
6	946	34,023	894
7	97	2,223	58
8	56	1,778	47
TOTALS	2,078	79,093	2,078

FOOTNOTES:

1. Frequency distribution retained, but adjusted to Total sample size.
2. From Table 3-2 of MTR-4158, reproduced as Table 3-1 herein.
3. Total sample is the total of the busy-hour sample from the four Center areas.

TABLE C-2: DATA FOR TOTAL SAMPLE

to appraise this data, we have calculated the mean, standard deviation, and coefficient of variation for each column of Table 2.6 of the 1673 report, using the updated frequency distributions of Table 3.10. These results are shown in Table C-3. These data were gathered at a time when the domestic message format was as follows:

$<<\downarrow A_1\ A_2\ A_3 <<\equiv$ header

(TEXT)

$\downarrow<<\equiv$

$$\left.\begin{array}{l} \equiv(12)\equiv \\ \equiv<\downarrow\downarrow \end{array}\right\} \quad \text{EOM}$$

where

$<$	- Carriage return
$\downarrow$	- Letters shift
A_1	- Alpha character
$\equiv$	- Line feed

Thus, every message had a constant overhead of at least 29 characters. In order to be conservative and consistent with the above observations, the message length model used in this study is composed of a constant overhead plus random length text, where the distribution for the text is exponential. Thus, the message length distribution for domestic traffic is a biased exponential with general form:

MESSAGE LENGTH STATISTICS
(Characters)

	STATION-COMPUTER	STATION-STATION	
		IFR	VFR
Mean	78.1	58.4	54.1
Standard Deviation	42	35	27.7
Variance	.54	.60	.512

TABLE C-3: DOMESTIC MESSAGE LENGTHS

$$FL_1(\ell) = \begin{cases} 1 - e^{-\left(\frac{\ell - k}{L_1 - k}\right)} & \ell \geq k \\ 0 & \ell \leq k \end{cases}$$

where,

k - Constant overhead

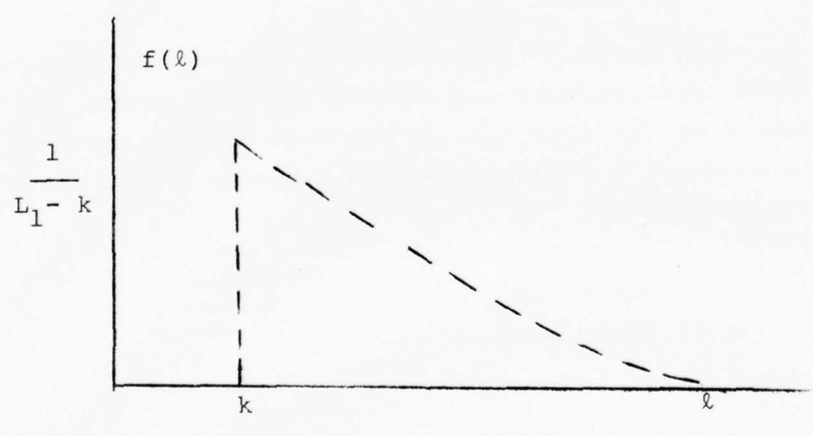
L_1 - Average total message length

$FL_1(\ell)$ - Prob (message length < ℓ characters)

The density function for this distribution is analytically expressed as:

$$f(\ell) = \frac{1}{L_1 - k} e^{-\frac{\ell - k}{L_1 - k}} \quad u(\ell - k)$$

and has the appearance



The mean is

$$\int_0^\infty \ell f(\ell)\, d\ell = L_1$$

The exponential distribution has a coefficient of variation equal to unity, and in general, provides conservative results in polling analysis; hence, its selection for the text model. The constant k should apparently be selected on the basis of the previously described message format, and the mean, L_1, selected on the basis of the reported data. However, since the data were gathered, the format has been changed to the following:

<<↓ A_1 A_2 A_3 <<≡

(TEXT)

↓<<≡

(7)≡

NNNN

This gives an overhead of 24 characters instead of 29. Thus, the overhead and overall message length averages reported in the data must be correspondingly reduced. With this in mind, a nominal domestic message length distribution is fixed at

k = 25 Characters
L_1 = 75 Characters

$$FL_1\ (\ell) = \begin{cases} 1 - e^{-(.02\ell\ -\ .5)} & \ell > 25 \\ 0 & \ell < 25 \end{cases}$$

As a worst case check for this distribution, note that the average message length found by using the largest number in each row of Table 2.6 is 82.97 characters, with the old format. This is very close to the mean of the above distribution. However, it should be noted that the average message length determined on the basis of data reported in MITRE WP-7229 is 89.4 characters, with the old format, or approximately 84 characters with the new format. The coefficient of variation squared determined on the basis of the WP-7229 is .6, whereas for the above distribution, the corresponding value is only .4. The data reported in WP-7229 resulted from measurements taken on circuits at Fort Worth and Los Angeles. As noted in MTR-1673, much of the information gathered in such experiments was invalid. However, as will be seen in the following sections, the distribution used to model NADIN messages is sufficiently general as to be consistent with all the above results.

C.2.2 AFTN

There is no information describing traffic within the AFTN report comparable to the MITRE reports on Service B. Field trips were made to several AFTN sites resulting in the collection of a significant amount of raw data. The Kansas City AFTN Switching Center appears to have the most comprehensive statistics, and is typical of a substantial portion of the U.S. operated AFTN facilities. Consequently, its data have been analyzed in some depth, and the results are used to portray several of the AFTN traffic characteristics. The most significant data were contained in a twenty-four hour history tape containing 13,265 AFTN messages. The analysis resulted in a histogram of the number of messages as a function of the message length, in quantum steps of five characters. A portion of this histogram is shown in Figure C-1. Based on this histogram,

we have calculated an average message length of 202 characters and a standard deviation of 217. However, the complete histogram shows a sizeable number of messages (980) as having lengths greater than 500 characters. Since such messages are normally sent in off hours, they should not be included in a busy hour model. Thus, considering only messages of length less than 500 characters, a new average of 154 characters is found, with a standard deviation of 102.

The histogram appears to be appropriately modeled by a biased exponential distribution as described earlier. The overhead constant was determined on the basis of a "least squares" fit of the histogram with the biased exponential. With this approach, the constant k was found to be 50 characters. Thus, the nominal AFTN message length distribution is fixed at:

$k = 50$ characters

$L_2 = 154$ characters

$$FL_2(\ell) = \begin{cases} 1 - e^{-\left(\frac{\ell - 50}{104}\right)} & \ell \geq 50 \\ 0 & \ell \leq 50 \end{cases}$$

This distribution is compared with the histogram in Figure C-1.

The AFTN message format, as discussed in Appendix A, has a nominal overhead of 66 characters. Thus, there is discrepancy between the nominal format requirements and the histogram. Based on other information (attachment to State Letter AN7/1.3.16 - 73/158) referenced by NATCOM, Kansas City, the discrepancy appears valid; indeed, some AFTN messages have less than the nominal 66 character format. This appears to have little impact on the investigation.

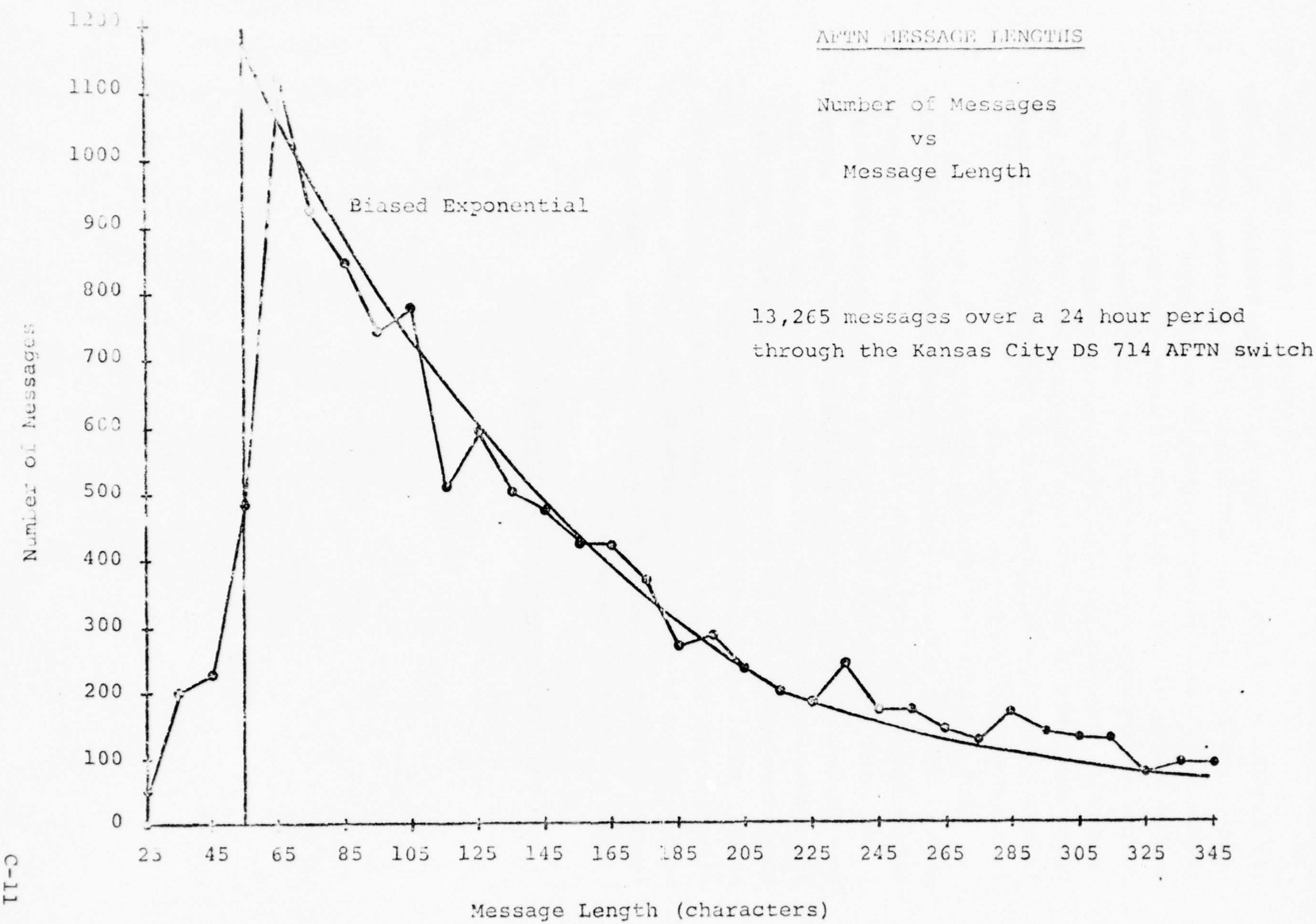


FIGURE C-1: HISTOGRAMS OF AFTN LENGTH MESSAGES

C.2.3 NADIN

The message length distributions developed above for Service B and AFTN are significantly different. With the initial implementation of NADIN utilizing existing terminals primarily in their existing roles, it would appear that a detailed design of the network should recognize this difference in the development of constraints for each category of the terminal. However, for the basic overall system analysis being conducted as part of this study, it was considered satisfactory to use a common distribution for all terminals that is based on the results achieved above.

Thus, considering that the majority of terminals in the network will be oriented towards domestic messages (including Alaska and Pacific AFTN which also perform Service B functions), and considering the evolving change to an AFTN-consistent format, a biased exponential distribution with a constant overhead of 40 characters and average message length of 110 characters was judged to be suitable to model the NADIN messages. This distribution represents a compromise between the distributions found for each system separately, with the overhead weighted in favor of the AFTN format, and the text length weighted in favor of domestic messages. This distribution is formally stated below:

<u>NADIN Message Length Distribution</u>

$$FL_N(\ell) = \begin{cases} 1 - e^{-\left(\frac{\ell - 40}{70}\right)} & \ell \geq 40 \\ 0 & \ell \leq 40 \end{cases}$$

C.3 MESSAGE ARRIVAL DISTRIBUTION

The arrival pattern of messages to either AFTN or Service B terminals is almost impossible to determine from the measured traffic statistics. However, it is logical to assume that, as in most communication systems, messages arrive randomly and independently. These are the basic attributes of a Poisson process. The message arrival distribution is primarily of interest in the performance analysis of the multidrop lines. These lines are appropriately modeled as single server queues, with the arrival pattern to each queue being the sum of the arrivals at the individual terminals on the line. It has been shown, in analysis of such queues, that if there are several inputs to the server, then the arrival distribution to the server can be approximated as a Poisson distribution regardless of the distribution types of the individual inputs. Thus, with this consideration and the preceding one, the arrival pattern of messages to the terminals in NADIN are modeled as Poisson. That is;

$$\Pr[r \text{ arrivals at location } i \text{ in interval of length } t] = Fi(r)$$

$$Fi(r) = \frac{1}{r!} e^{-R_i t} (R_i t)^r \qquad i=1,2, \ldots .$$

where R_i is the average arrival rate of messages at location i. The values to be used for R_i are considered in the next section.

It should be noted that the above distribution has a coefficient of variation squared equal to .4. For conservative analysis, where this distribution is used, a value of .6 was used instead.

C.4 MESSAGE ARRIVAL RATES

The NADIN network must provide acceptable response time under the traffic loads anticipated for the next ten years. To appraise the performance of network designs in meeting this requirement, it is first necessary to define and quantify the "acceptable response time" and "anticipated traffic loads". In this appendix, two basic characteristics of the traffic model for the network have been established. In this section, the portion of the traffic model most commonly referred to as the "load" is developed. In Appendix D, the "response time" is defined, and the traffic model developed in this appendix is used to appraise network performance.

The "load" on a network is a measure of the amount of activity in the network. With the message length distribution and arrival pattern given, the load may be defined as the average arrival rate of messages from outside the network to the entry points of the network. To use this information to determine the necessary capacity of network components, it is helpful to know some of the characteristics of the flow pattern within the network. In particular, referring to Figure C-2, it is helpful to know how much of the traffic for a circuit such as A may be transmitted from the terminals on the circuit (1, 2, 3, 4), and how much may be transmitted to the terminals from the CF. Furthermore, to determine the size of the circuits between the CF's and the SC's, it is helpful to know how much of the traffic is held locally, and how much is sent over the part of the network interconnecting CF's. Detailed information on the network flow pattern is

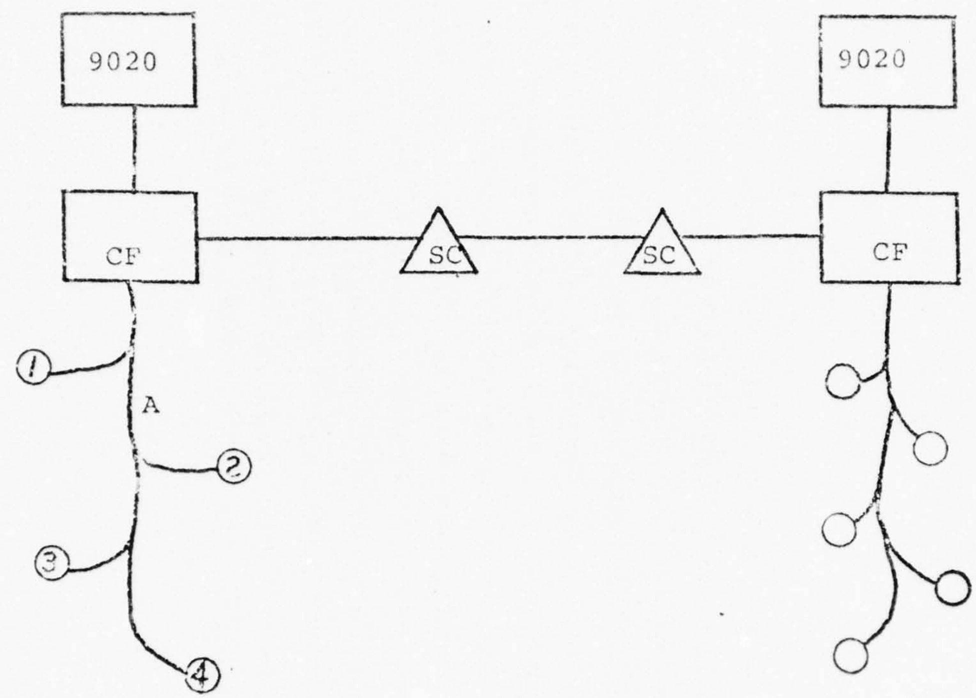


FIGURE C-2: FUNCTIONAL TRAFFIC FLOW MODEL

difficult to obtain and is subject to change over time, and as noted earlier, is not appropriate for network design. However, some general characteristics of the type described above are necessary and if they cannot be determined by observation, reasonably conservative assumptions should be used in the design process in order to develop rational designs. These characteristics are the subject of the next section. In this section, we will characterize the network load in terms of the total amount of traffic, both originating and received, that a terminal experiences. Division of the traffic will be discussed in the next section.

The NADIN, like most networks, will experience periods of peak activity. The acceptability of a network design will be based on its performance during this peak period. In NADIN, this period is appropriately selected as an hour, and the traffic load will then be expressed in terms of the "busy hour". The data describing traffic levels in the existing networks is usually expressed in characters per hour. Knowing the message length distribution, this can easily be related to messages per hour when necessary for analysis. Thus, the traffic loads developed in this section will be in terms of characters per busy hour. To develop the load projections, data available for the existing systems will be used.

C.4.1 Service B

Traffic studies and projections for the Service B network have been produced by the MITRE Corporation as report numbers 4158 and later, 1673. A basic description of the 4158 report and its use for traffic projections for Area B terminals is contained in Telcom Report No. DOT/FAWA2707. The results contained in MTR-4158 were based on a number of field experiments conducted by MITRE in conjunction with the

FAA. However, the observation periods during the field trips could not be arranged to be of the planned duration and later experiments, as reported in 1673, showed inconsistent results. This led to a general conclusion that "the routing information contained in the originally published results of MTR-4158 are invalid and all are cautioned not to use that data." However, the second set of experiments did verify that the total message traffic projections could be validly updated to represent current FAA projections of air traffic activity. Applying the suggested technique for updating this information, the traffic projections for the Category 1 locations are obtained as listed in Appendix H. The detailed traffic projections are only available up to 1980. Correlation with current FAA aviation forecasts indicates that 1984 traffic can be estimated as approximately 35% more than 1980 traffic. Based on the broadening scope of NADIN services and to insure that the network is insensitive to variations in traffic, this estimate is taken to be 90%. The terminals located in ARTCC's are assumed to have a 1973 base traffic estimate of 2,333 characters per busy hour. This again is based on broadening in scope of the NADIN. Traffic projections for the other years are based on correlations with the other traffic projections.

The terminals at Category 2 locations (military air bases) are estimated to handle 40-60 flight plans per day per station, as noted in Telcom Report No. FAA-RD-72. Based on this level of activity, the report develops a busy hour estimate of 1000 characters. The FAA aviation forecasts indicate a stable level of military flights over the 1984 frame. Thus, this projected traffic is held constant for all years. This traffic is listed for the Category 2 locations in Appendix H.

The locations in Category 3 are in air carrier offices served by either AFTN or Service B circuits. The terminals on these circuits are bunched at airports and can be effectively replaced by a single composite terminal in the design process. For those locations on Service B circuits, the composite traffic can be estimated in the same manner as in Telcom Report No. DOT/FAWA2707. These projections are listed in Appendix H.

C.4.2 AFTN

Unfortunately, there is no information on the AFTN terminal traffic comparable to MITRE reports for Service B. The best information to date has been that provided in the quarterly traffic reports generated for the AFTN circuits by a one day sampling process instituted on a quarterly basis. A typical page from such a report is shown in Table C-4. Of particular interest are the total group activity (a group is six characters), total message activity, and the peak hour message activity. Using the following formula, these numbers can easily be converted to characters per peak (busy) hour:

Chr./busy hour = [(DTG X 6) /DTM] X PHM.

Where:

DTG = Daily Total Groups

DTM = Daily Total Message

PHM = Peak Hour Messages

To project future traffic levels, the 1973 traffic data has been increased by an amount proportional to the projected increase in flight services as reported in the FAA aviation forecasts for the fiscal years 1974-1985. As with the Service B traffic, the 1984 level of traffic has been estimated as 90% more than the 1980 traffic in order to ensure in-

sensitivity to variations in the traffic. Similarly, for airline circuits with terminals bunched at airports, a composite node has been used. For geographically extended circuits with multiple terminals, the traffic has been evenly divided among the terminals. The results are shown in the listing in Appendix H.

C.5 MESSAGE ROUTING

Referring to Figure C-2, messages originating at a terminal may be destined to:

1. A terminal on the same circuit.
2. A terminal on a different circuit served by the same CF.
3. The NAS 9020 computer at the CF.
4. A terminal served by a different CF.

The division of the traffic over these four categories could affect the appropriate sizing of the communication channels between CF's and SC's, between SC's, and the constraints for the number of terminals on a circuit. However, accurate information on the routing of the traffic is very hard to obtain, as noted by MITRE in MTR-1673; furthermore, it should be considered as subject to change. Thus, for appropriate sizing of the communication channels and development of circuit constraints, conservative assumptions should be made coupled with sensitivity analysis. These assumptions and the related analysis are the subject of Appendix D.

CHNL NMBR	CKT NMBR	CORRE-SPOND-ENT	CKT TYPE	CKT SPEED (WPM)	CKT SERVICE-ABILITY	DAY TOTAL GROUPS		DAY TOTAL MESSAGES		PEAK HOUR MESSAGES		% OF INCOMING MESSAGES REQUIRING RELAY TO		
						Tran	Recd	Tran	Recd	Tran	Recd	2 CKTS	3 CKTS	4 or more CKTS
061	GT8290-061	KRWAYA KDCCZR KDCCZQ KRWA1	LLTSX	100	S 70.2 R 97.3	1,994	1,948	28	16	13/005	18/004	25	-	-
062	FAA11062	KJFKYF	LLTDX	100	S 99.8 R 99.8	30,128	5,292	579	173	22/047	02/022	17	4	26
065	FA11065	KJFKZ_ KBOSZ_	LLT/TO	100	S 99.5	15,228		247		21/018		-	-	-
066	FA11066	KJFKYM	LLTDX	100	S 99.7 R 99.7	13,628	320	205	7	09/013	00/003	14	-	86
067	FA11067	KJFKYM	LLTDX	100	S 98.9 R 98.9	1,974		88		21/006		-	-	-
069	FA11069 MP-1	KJFKPA/ SR/YJ	LLTSX	100	S 98.6 R 98.5	17,726	4,268	454	62	16/035	22/015	28	28	31
070	FA11070 MP-2	KJFKAF/ AA/SN	LLTSX	100	S 99.7 R 99.7	16,844	4,104	425	41	18/032	21/010	46	10	15
071	FA11071 MP-3	KJFKTW/ CL/IB/ JL/CA/XH	LLTSX	100	S 99.9 R 99.9	14,678	870	317	14	22/021	12/004	7	21	36
072	FA11072 MP-4	KJFKLY/ SB/AR/ OV	LLTSX	100	S 99.8 R 99.8	17,452	2,268	422	42	18/029	22/005	45	38	-

TABLE C-4: TYPICAL PAGE OF AFTN TRAFFIC REPORT

APPENDIX D

PERFORMANCE ANALYSIS

D.1 INTRODUCTION

For a network such as NADIN, "performance" is usually defined in terms of the time it takes a message to traverse the network from entry to exit (which will be called traversal time) and the traffic level the network experiences (which is called the throughput). These two attributes are interrelated, therefore performance is usually characterized by the average traversal time as a function of the throughput.

In general, network design is oriented towards achieving an "acceptable performance" specified as an average traversal time for a given throughput. However, in NADIN many of the physical aspects of the network affecting performance are fixed (i.e., Model 28 teletypes). Without knowing the impact of these limitations it is very difficult and even dangerous to specify, a priori, a required performance for the network design. An appropriate approach is to investigate the factors that will contribute to the traversal time in terms of the given equipment constraints and, on the basis of this investigation, develop design constraints and requirements that are consistent with the overall network objectives and good engineering. It is this course which is taken here.

D.2 TRAVERSAL TIME

The traversal time of a message is precisely defined as the interval of time from the instant at which the message is ready for transmission at its entry point until

the last character of the message is received at its exit point. The entry and exit points of the network are generally thought of as terminals. However, they also include the NAS 9020 computers and possibly the concentrators or switches (i.e., administrative messages timed for release to report scheduled outages for maintenance, etc.). The possible components of traversal time are explained in terms of Figure D-1. This figure is a functional portrait of NADIN as a network of queues, showing two concentrators (C_1 and C_2) interconnected by a switching center (S). For this explanation, the concentrators are assumed to have switching capability, not all messages require journaling, and all terminals are on half-duplex lines. This is the most general case, and does not necessarily correspond to the NADIN recommendation. Other assumptions can be similarly modeled. The situation with a multiplexer is explained as a simplification of this portrait.

D.2.1 Network Operation

To explain the operation of the network, the paths a message may follow are considered. Consider a message arriving at a terminal, such as T_1(1). The "arrival" is the act of the operator in initiating the terminal equipment so that the message will be automatically transmitted when the terminal is polled. The traversal time interval for the message begins when the operator is done. The concentrator C_1(4) processes a polling list for the line (2). When terminal T_1 is reached on the list, the terminal is polled and its message is transmitted. If the message does not require journaling and is directed to a terminal on the same circuit, the appropriate terminal receives the transmission and the operation is complete. In this case, the traversal time is simply the delay in the polling cycle reaching the terminal plus the time required to transmit the message.

If the message requires journaling or is due for a terminal on another circuit, it is received by the concentrator (C_1), buffered, and placed on the input queue (3). All messages received by the concentrator from its terminals are placed on a common input queue and processed on a priority basis with a FIFO discipline within priority classes. The processing consists primarily of routing, with code conversion if appropriate. If the message requires journaling or is directed to a terminal not connected to the concentrator, it is placed in the output queue (5) for the high speed line (6) to the switching center (8). Otherwise, the message is simply placed in the output queue (such as 7) for the appropriate circuit. Note that a circuit connecting terminals to the concentrator is modeled as half-duplex, thus providing messages to the common input queue (3) and also transmitting messages from the appropriate output queue (such as 7). The necessary coordination is provided by the concentrator software. The traversal time ends when the last character of the message is removed from the output buffer and completes transmission over the circuit.

When a message is transmitted from the concentrator (4) over the high speed line (6), it is received by the switching center (8), buffered, and placed on the common high-speed line input queue (9). All messages received over high-speed lines by the switching center are placed on this queue and are processed on a priority basis with a FIFO discipline within priority classes. The processing consists of journaling, if appropriate, and routing. If the message is destined for a terminal connected to the switching center, the message is simply transferred to the appropriate output queue (such as 10). Otherwise the message is transferred to an output queue for one of the high speed lines (such as 11). The high

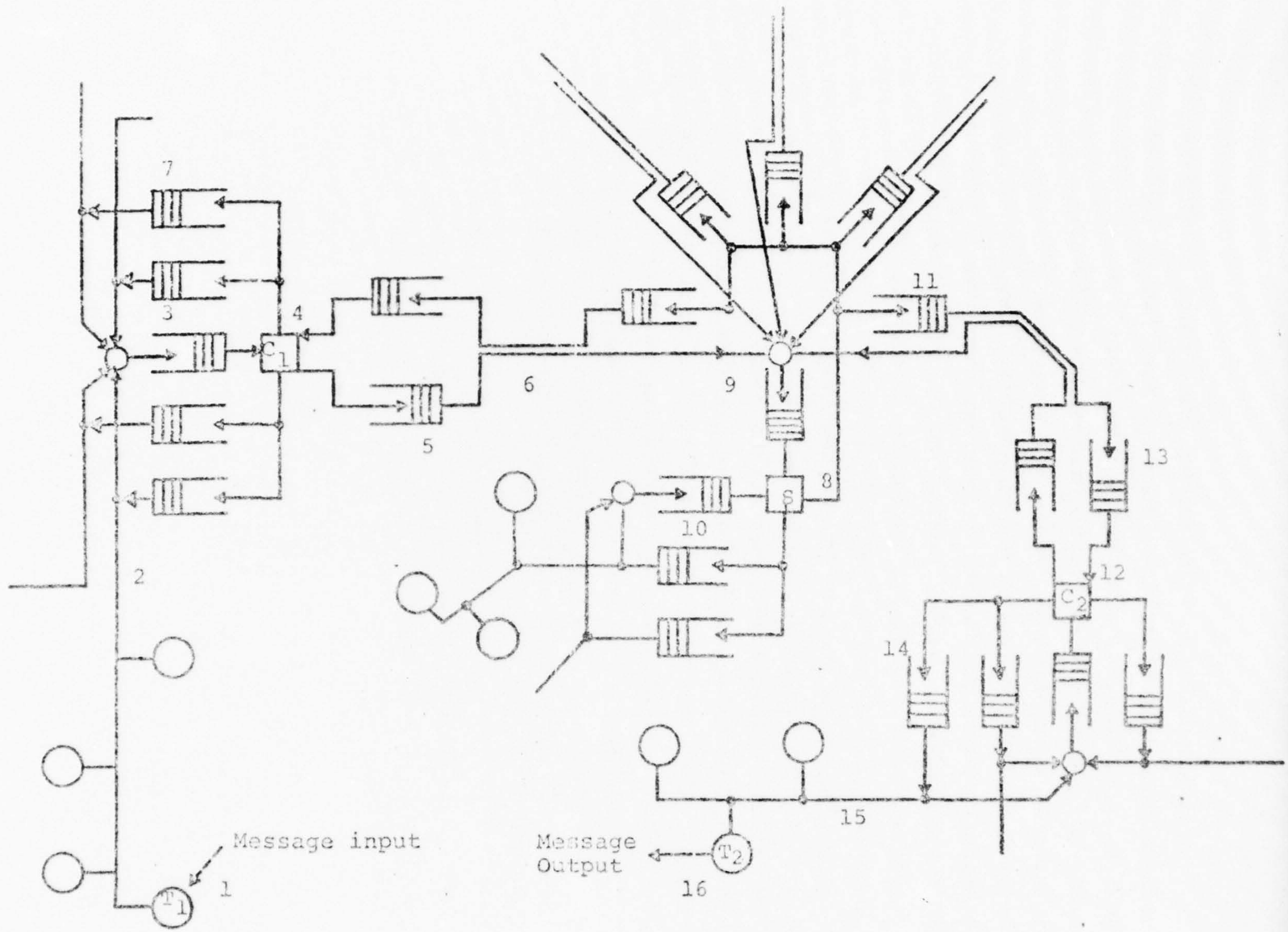


FIGURE D-1: QUEUEING MODEL FOR NADIN

speed line may lead to another switching center, in which case the processing described above is repeated, or to a concentrator as shown in the figure.

The message is received by the concentrator C_2 (12), buffered, and placed in the high-speed line input queue (13). The concentrator processes the message on a priority basis with a FIFO discipline within priority classes. The processing consists primarily of determining over what circuit the message is to be sent and performing code conversion if appropriate. The message is then placed in the appropriate circuit output queue (14). When the last character is received over the low speed line, (15) by the appropriate terminal (16), the traversal time is ended.

D.2.2 Traversal Time Components

As may be seen from the above discussion, the traversal time may consist of many components depending on the path the message follows from entry to exit. The time required for several of the events in the passage of a message may also be overlapping. This is exemplified by the case of a message originating at a terminal using five level Baudot code on a 75 bps circuit and destined for a terminal using seven level ASCII code on a 1200 bps circuit connected to the same concentrator. Typical timing relations that may be involved are shown in Figure D-2. At t_I the message arrives at the terminal, where it waits to be polled. After the terminal is polled, message transmission begins. After the header is received, an entry is placed on the input queue to indicate the message is ready for routing. The header may be processed concurrently with reception of the rest of the message. The processing of the header indicates a routing to the other circuit and a requirement of code conversion. The code conversion commences immediately on the partially received message and

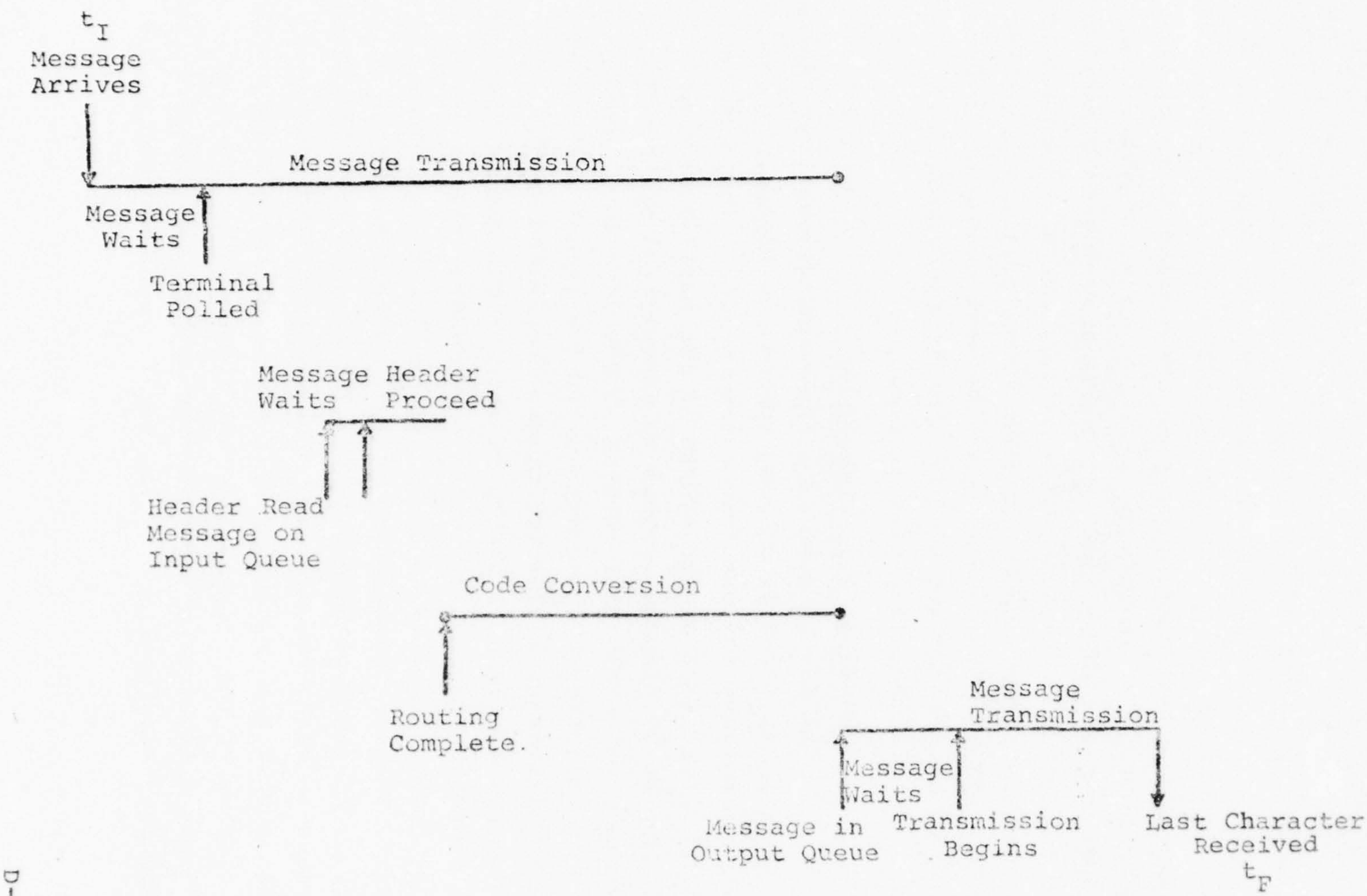


FIGURE D-2: TIMING RELATIONS IN MESSAGE TRAVERSAL

soon reaches the point of converting each new character as received. Thus, when the last character is received, within microseconds the message processing is complete and an entry is made in the output queue. The message transmission takes much less time on the 1200 bps circuit than on the 75 bps circuit and when the last character is received by the destination terminal, at time t_F, the operation is complete. The traversal time is simply, $t_F - t_1I$ and as can be seen in this case, can be found as simply the sum of the time required to move the message from the originating terminal to the concentrator, plus the time required to move the message from the concentrator to the destination terminal. It should be noted that code conversion could be done as suggested or, as each character is received at the concentrator, it could be converted to a standard code and, if required, each character could be converted on output to the circuit. However, in either of the procedures, the code conversion would occur on a low level, interrupt basis concurrently with message transmission operations and would not add to the traversal time. This leads to a general observation about <u>properly</u> designed and sized communication processors for a network such as NADIN: such processors add an insignificant amount of delay to message traversal time in comparison to the basic delays of transmission time and the time spent waiting for availability of transmission facilities. Consequently, in analyzing the components of delay that may contribute to traversal time, attention will be paid only to the primary sources of delay. These include:

> Terminal-Concentrator Time (T_{TC}): Total time from the arrival of a message at a terminal until reception of the last character by the concentrator.
>
> Concentrator-Switch Time (T_{CS}): Total time from availability of a message for transmission from

a concentrator to a switch until the last character is received at the switch.

Switch-Switch Time (T_{SS}): Total time from the availability of a message at one switch until the last character is received at the second switch.

Switch-Concentrator Time (T_{SC}): Total time from the availability of a message at a switch until the last character is received at the concentrator.

Concentrator-Terminal Time (T_{CT}): Total time from the availability of a message at a concentrator until the last character is received at the terminal.

The traversal time for the situations described earlier can now be simply expressed:

- Terminal-to-Terminal on same circuit:

$$T = T_{TC}$$

(as the other terminal hears the message at the same time the concentrator does).

- Terminals on different circuits of same concentrator:

$$T = T_{TC} + T_{CT}$$

- Terminals at different concentrators connected to the same switch:

$$T = T_{TC} + T_{CS} + T_{SC} + T_{CT}$$

- Terminals at different concentrators connected to different switches:

$$T = T_{TC} + T_{CS} + T_{SS} + T_{SC} + T_{CT}$$

To make a quantitative appraisal of the traversal time and to extract appropriate constraints, the various components identified above are considered below. Prior to this consideration, a note should be made about the situation with multiplexers. In this case, there is no delay component of concentrator-to-switch; a message goes directly from terminal to switch over the circuit on which it is placed. The multiplexer is operationally transparent (except for perhaps a single character buffer delay). Thus, the multiplexer will, in general, have slightly better traversal time. However, it requires I/O processing by the switch for each circuit since all intercircuit traffic within a region is directed to the central switch for processing. This requires a higher bandwidth, hence more costly line from the region to the switch than does a concentrator. It also requires greater processing capacity at the switch than does a concentrator. These effects will be quantitatively appraised later.

D.3 TERMINAL CIRCUITS

In this section, consideration is given to the timing involved in messages being sent from a terminal to its concentrator and from a concentrator to one of its terminals. Three situations are identified:

1. Model 28 teletypes on 75 bps circuits using Service B procedures (P_1 procedures as defined in Appendix A).

2. Model 28 teletypes on 75 bps circuits using AFTN procedures (P_2 procedures as defined in Appendix A).

3. ANSI consistent terminals on 1200 bps circuits using ANSI consistent procedures.

These three cases will be considered independently below. However, there are basic aspects common to all three which are considered now.

D.3.1 Basic Analysis

Two basic items of timing information are desired: the average time from the arrival of a message at a terminal until the last character is received by the concentrator, called the polling time, and the average time from the availability of a message at a concentrator until receipt of the last character by the terminal, called the delivery time. The polling time distribution and delivery time distribution depend on many factors including: the polling disciplines, hardware capabilities, overhead traffic, line speeds, message length distributions, message arrival distributions, buffer sizes, number of buffers, etc. Even if all factors involved are precisely defined, it is almost impossible to obtain a precise analytical portrait of the system due to its complexity. Similarly, simulation without simplification is very difficult and very costly; thus it is not attractive. However, it is possible to obtain reasonably conservative results by making appropriate simplifications. For the basic system design considerations involved here, an analytical approach gives sufficiently good results to be favored over the more difficult and costly simulation approach.

D.3.1.1 Timing Definitions

On a multidrop line using any of the three control procedures outlined in Appendix A, when any station is transmitting, no other station on the same line can transmit. Therefore, the multidrop line can be viewed as the single server for the messages from the terminals on the line. The situation may be modeled as a single server queue in which messages join the queue upon their arrival at a terminal (or at the concentrator).

However, the service discipline is not FIFO as is customary, but rather determined by the polling cycle, and messages at the concentrator are given non-preemptive priority. Furthermore, the service time will depend on not only the length of the message, but also on the effect of polling terminals without messages prior to polling a terminal with a message. With moderate simplifications, these factors can all be accommodated in the analytical approach.

When a terminal is polled, one of two events may occur (assuming the terminal is operable and transmission errors do not occur); the terminal may have a message, at which time it is transmitted, or the terminal does not have a message. The former is called a positive poll and requires a time interval whose duration depends on constant factors (modem request-to-send, clear-to-send delay, transmission of polling code, etc.) plus the message length. This time may be expressed as:

$$T_{PP} = T_{PPC} + T_L$$

When a terminal has no message to transmit, the polling of the terminal is called a negative poll and requires a constant time T_{NP}. When a concentrator transmits a message (assuming the circuit is available), again there is a constant circuit preparation time plus a time depending on message lengths, or:

$$T_C = T_{CC} + T_L$$

Using the above timing definitions, expressions can now be derived for the average polling time and the average delivery time.

D.3.1.2 Waiting Time

One of the most general, and common, relations used in queueing analysis is the Polloczek-Khintchine formula relating the average waiting time of customers to the through-

put for single server queues with Poisson arrivals and general service time distribution. With,

λ - Average arrival rate (msg/sec).

$\bar{x}$ - Average service time of a message (sec/msg).

$\overline{X^2}$ - Second moment of service time.

$C^2 = \dfrac{\overline{X^2} - \bar{X}^2}{\bar{X}^2}$ - Coefficient of variation squared.

$\zeta = \lambda \bar{X}$ - Utilization.

The average waiting time is expressed as:

$$W = \frac{1}{\lambda} [\zeta + \frac{\zeta^2(1 + C^2)}{2(1 - \zeta)}]$$

$$= \bar{X} + \frac{1/2 \ \lambda \overline{X^2}}{1 - \lambda \bar{X}}$$

The average waiting time W is the average time from a message joining the queue until its final character has been completely transmitted. The service time X of a message is basically the time required to transmit the message and depends on its length in characters and the line transmission rate. However, as noted earlier, to use this formula properly, the service time must also include the impact of polling (i.e., the possibility of several negative polls before the poll of a terminal with a message). This impact will be evaluated shortly.

The general formula given above can be extended to handle queues with non-preemptive priorities, that is, queues in which the next message selected for transmission is the one with the highest priority, but each message selected is transmitted to completion before transmission of the next message (even if of higher priority) is initiated. Thus, with:

λ_i - Average arrival rate of messages with priority i (i < j implies i of higher priority than j).

$\bar{X}_i$ - Average service time of a message with priority i,

$\overline{X_i^2}$ - Second moment of service time,

the average waiting time of a message with priority j may be expressed as:

$$W_j = \bar{X}_j + \frac{1/2 \sum_{i=1}^{N} \lambda_i \overline{X_i^2}}{\left(1 - \sum_{i=1}^{j-1} \lambda_i \bar{X}_i\right)\left(1 - \sum_{i=1}^{j} \lambda_i \bar{X}_i\right)}$$

where N is the number of priority classes. Note that the second moment of the service time can be found from the average service time and the coefficient of variation.

In order to relate the above formula to the analysis of the polling situation, it is first necessary to examine the service discipline of the queue. Messages which arrive at a concentrator are transmitted immediately after completion of the current polling event (whether a negative poll or a positive poll). Thus, these messages are given non-preemptive priority over those which arrive at the terminals and which must wait to be polled. The messages which arrive at the terminals are not necessarily transmitted on a first come-first serve

basis, due to the polling operation. However, since no preference is given to shorter messages, the average waiting time is the same as that of a first come-first served (i.e., First In-First Out - FIFO) service discipline. Thus, for the queueing situation of interest here, two priorities are identified: priority one is given to messages which arrive at the concentrators and priority two is given to messages which arrive at the terminals. Thus, the average waiting times can be expressed as:

$$W_1 = \bar{X}_1 + \frac{1/2(\lambda_1 \overline{X_1^2} + \lambda_2 \overline{X_2^2})}{1 - \lambda_1 \bar{X}_1}$$

$$W_2 = \bar{X}_2 + \frac{1/2(\lambda_1 \overline{X_1^2} + \lambda_2 \overline{X_2^2})}{(1-\lambda_1 \bar{X}_1)(1-\lambda_1 \bar{X}_1-\lambda_2 \bar{X}_2)}$$

Consideration is now given to the proper definition of the service times X_1 and X_2.

D.3.1.3 Service Time

The service time of messages arriving at the concentrator is the time from the presence of the message at the head of the queue until completion of its transmission. In light load situations, when a message arrives at the concentrator, it is immediately at the head of the queue and must wait only for completion of the current polling event before it is transmitted. If the event is a negative poll, this time should be considered as part of the service time. If the event is a positive poll, the time is considered as part of the service time of a message transmission in progress and is already incorporated in the formula. In the light load situation, when

a message arrives at the concentrator, the vast majority of events in progress will be negative polls and, since the messages arrive at random, the average delay will be simply one-half the negative polling time. Thus, for the light load situation, the average service time for messages arriving at the concentrator, $\bar{X}_1$, is:

$$\bar{X}_1 = 1/2T_{NP} + T_{CC} + \bar{T}_L$$

where $\bar{T}_L$ is the average message transmission time. For heavy load situations, an average factor somewhat less than $1/2\ T_{NP}$ will be present. Thus, $\bar{X}_1$ as described above, will be used as a conservative expression for the average service time. The variance is simply:

$$\overline{X_1^2} - \bar{X}_1^2 = \frac{T_{NP}^2}{3} + \text{Var. } (T_L)$$

The service time of messages arriving at the terminals must include the time taken for polling as well as the time for transmission. In order to determine the average service time, the average number of terminals polled before finding a terminal with a message must be determined. For the light load case with M terminals and assuming the messages arrive equally likely among the terminals, an average of (M-1)/2 terminals will be polled before the terminal with the message is polled. Thus, the average service time of messages arriving at the terminals for the light load case is:

$$\bar{X}_2 = \frac{M-1}{2}\ T_{NP} + T_{PPC} + \bar{T}_L$$

For heavy load situations an average factor somewhat less than $((M-1)/2)\ T_{NP}$ will be present. Thus, $\bar{X}_2$ as described above will be used as a conservative expression for the average service time. The variance is simply;

$$\overline{X_2^2} - \bar{X}_2^2 = \frac{M^2 - 1}{12} \quad T_{NP}^2 + \text{Var. } (T_L)$$

D.3.2 Service B Circuits

The basic formulas developed in the preceding section can now be used to appraise performance characteristics of Service B circuits. The time for a positive poll in Service B contains the following components:

T_P - Time to send polling inquiry.

T_r - Time for terminal to respond.

T_L - Time to transmit message.

T_e - Idle time.

Thus, the positive polling time, T_{PP}, is,

$$T_{PP} = T_{PPC} + T_L = T_P + T_r + T_e + T_L$$

For a negative poll, the circuit time has two basic components; the time required to send the polling inquiry and the time-out delay. Thus,

$$T_{NP} = T_P + T_d$$

The results of a study by MITRE to quantify the above timing components are contained in MTR-1673. These results indicate that for existing equipment and operations, appropriate values are:

T_P = .8 seconds

$T_r + T_e$ = 2.1 seconds

T_d = 1.4 seconds

The report also considers the case where existing hardware is adjusted for optimum performance and achieves the values:

$T'_p = .8$ seconds

$T'_r + T'_e = 1.2$ seconds

$T'_d = 1.0$ seconds

Thus, the basic polling times are:

- Existing

  $T_{PP} = 2.9 + T_L$

  $T_{NP} = 2.2$

- Optimized

  $T'_{PP} = 2.0 + T_L$

  $T'_{NP} = 1.8$

Using the above results, coupled with the common message length distribution developed in Appendix C and a transmission capacity of 75 bps, the service times for the formulae developed in the previous section can be developed. However, because the existing system is based on delivering messages from the high-speed circuit interface by polling, rather than on a priority basis as with a concentrator, there is no value determined for circuit preparation time for the concentrator. This can be conservatively estimated as:

$T_{CC} = T_r + T_e$

Thus, with existing equipment,

$T_{CC} = 2.1$ seconds

and with optimized equipment,

$T'_{CC} = 1.2$ seconds

The basic service times are then:

- Existing (M = number of terminals on circuit)

$\bar{X}_1 = 14.2$ seconds

$\overline{X_1^2} = 275.9$

$\overline{X_2} = 1.1M + 12.8$ seconds

$\overline{X_2^2} = 1.6M^2 + 28.2M + 236.0$

- Optimized

$\bar{Y}_1 = 13.1$ seconds

$\overline{Y_1^2} = 245.3$

$\bar{Y}_2 = .9M + 12.1$ seconds

$\overline{Y_2^2} = 1.1M^2 + 21.8M + 218.7$

Using these values, several curves of delay versus throughput have been generated and are portrayed in Figures D-3 through D-6. The terminal delay is the average time from the availability of a message at a terminal until the last character is received by the concentrator. The concentrator delay is similarly defined. The throughput is given in thousands-of-characters per hour, based on the average message length of 110 characters as developed in Appendix C.

Figure D-3 shows the terminal delay curves for circuits with 2, 5, 10, and 15 terminals, where the traffic on the circuit is evenly divided between messages from terminals to the concentrator and messages from the concentrator to the terminal. Figure D-4 shows the concentrator delay curves for the same circuit conditions. Note that the concentrator delays

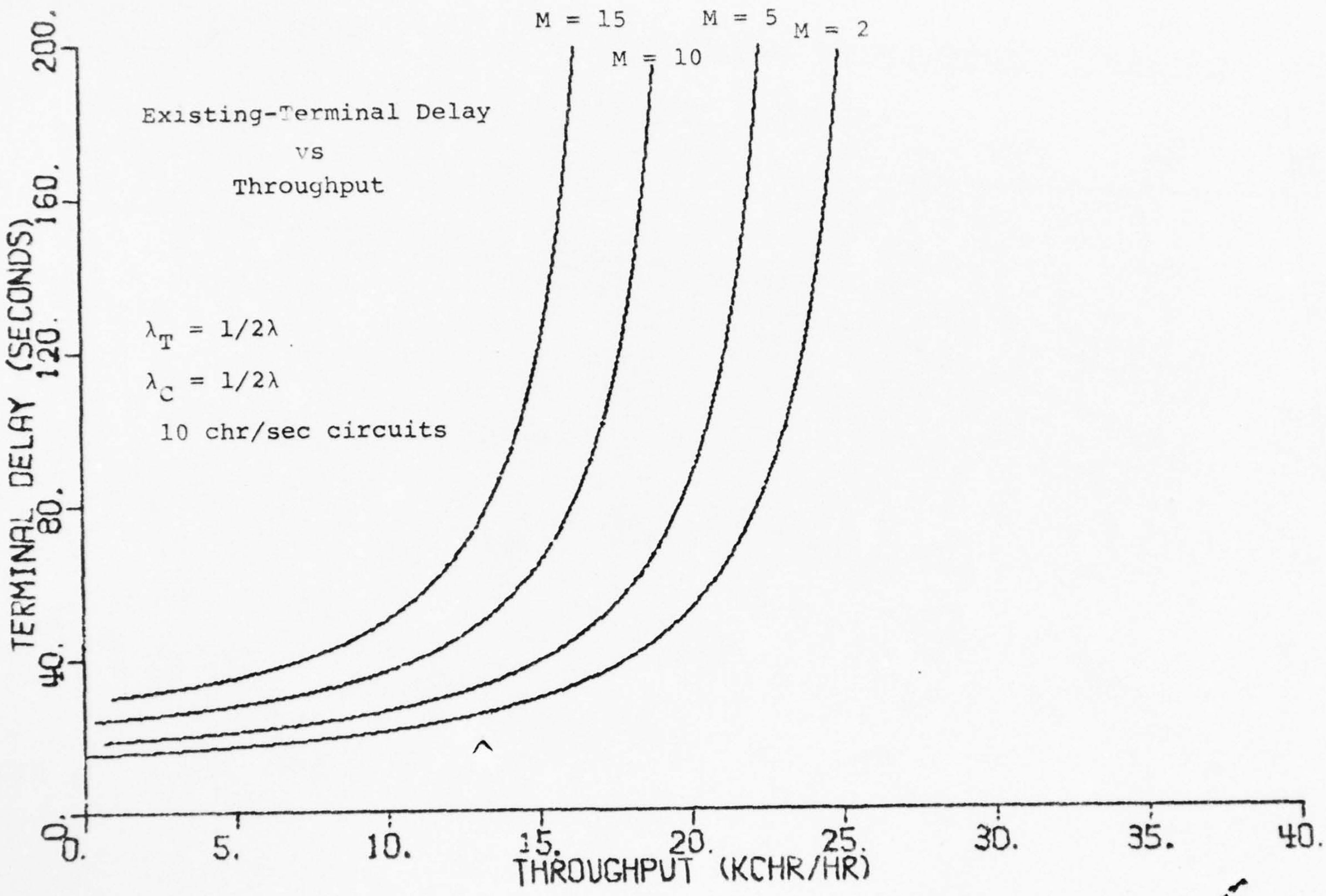


FIGURE D-3: TERMINAL PERFORMANCE - EXISTING SERVICE B EQUIPMENT

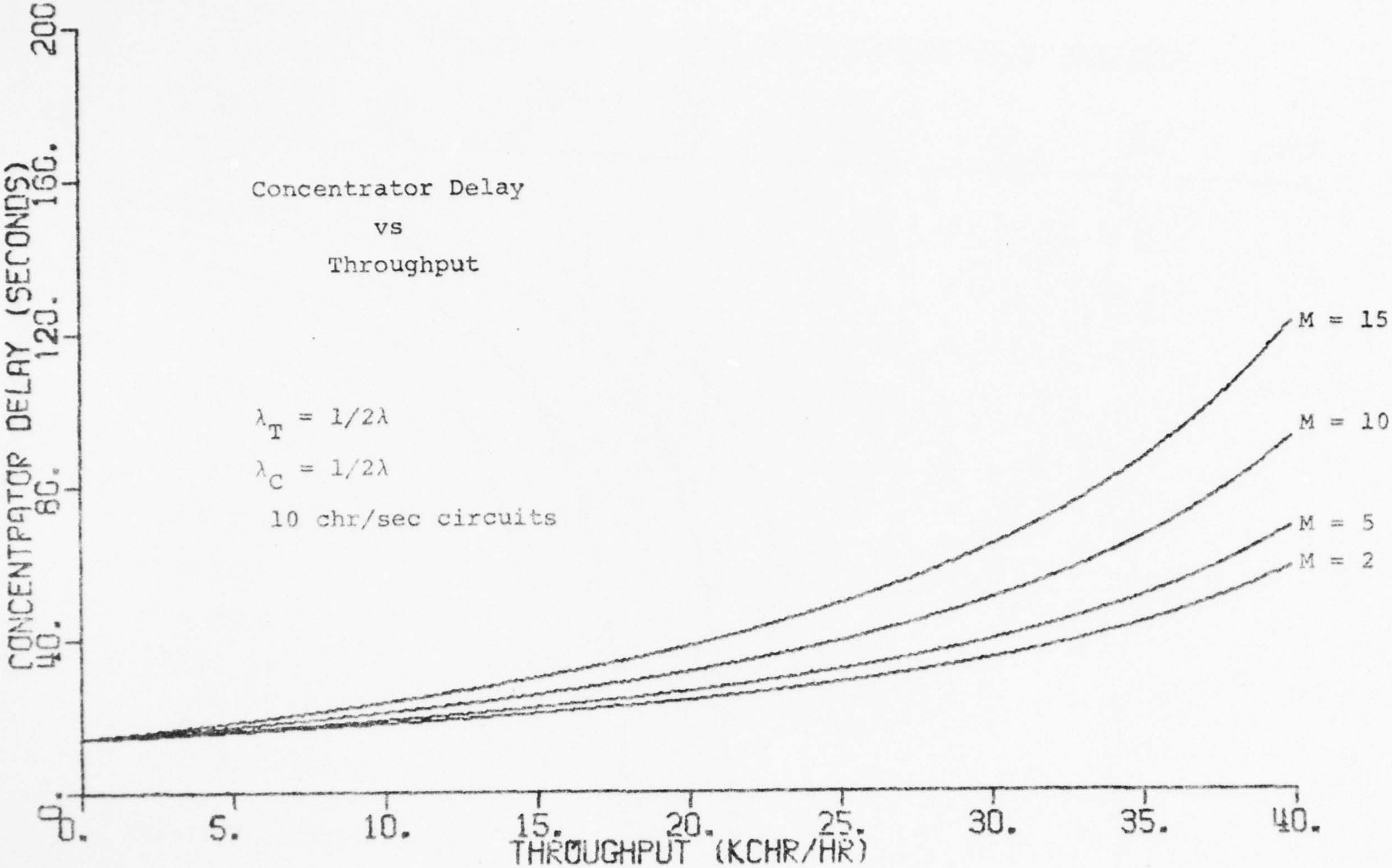


FIGURE D-4: CONCENTRATOR PERFORMANCE - EXISTING SERVICE B EQUIPMENT

are substantially better than the terminal delays. This reflects the fact that messages at the concentrator do not have to wait until a particular position on the polling list is encountered. It should be noted that this provision reduces the overall message delays on the circuit, as it simply uses the fact that the presence of messages at the concentrator can be recognized without having to do the polling operation.

The terminal delay curves for the optimized equipment are shown in Figure D-5 for the same circuit conditions as described above. The optimized curves are very close to a 2 KCHR/HR shift of the existing equipment curves. The sensitivity of the curves to the division of traffic on the circuit is protrayed in Figure D-6. Three curves for a five terminal circuit are portrayed, with terminal traffic ranging from 20% to 80% of the total traffic. Note that the curves appear quite insensitive to this variation. This is due to a number of compensating factors. When terminal traffic is a high percentage, there are fewer occurrences of delays in the polling cycle due to outgoing messages and less time between positive polls. When terminal traffic is a low percentage, a higher percentage of the messages are serviced with priority which have a correspondingly shorter service time. Thus, there is less queueing delay for the nonpriority messages. This insensitivity confirms the validity of using the even traffic division in the remainder of the analysis.

The curves discussed above are for total delay, or waiting time, which is composed of the queueing time plus the service time. In the common queue with Poisson arrivals and exponential service time, the increase in queueing time (the curves above shifted to the origin) for an increase in traffic is always more than proportional, i.e., a doubling of traffic will more than double queueing time. Furthermore, the rate of increase is also more than proportional. That is

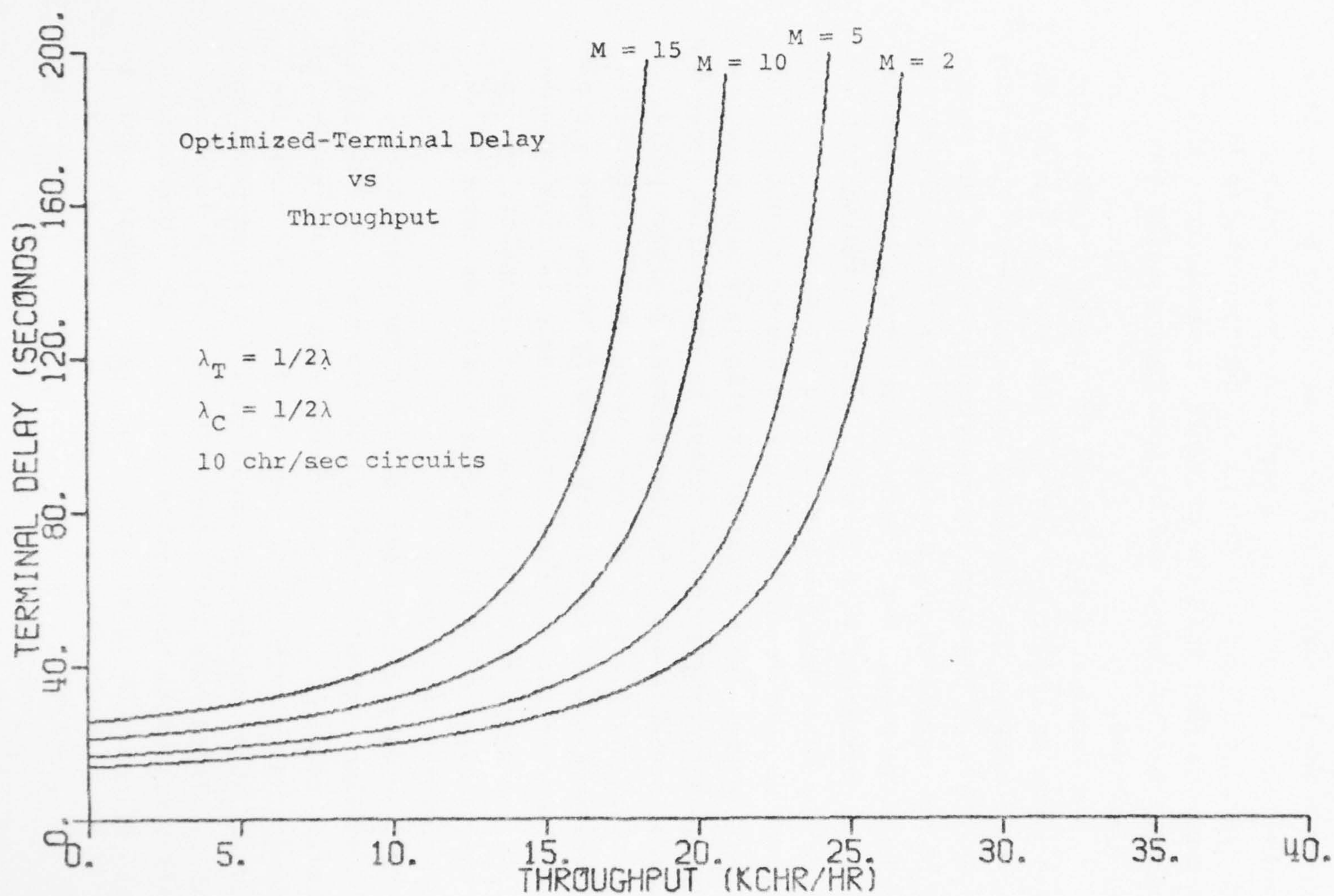


FIGURE D-5: TERMINAL PERFORMANCE - OPTIMIZED SERVICE B EQUIPMENT

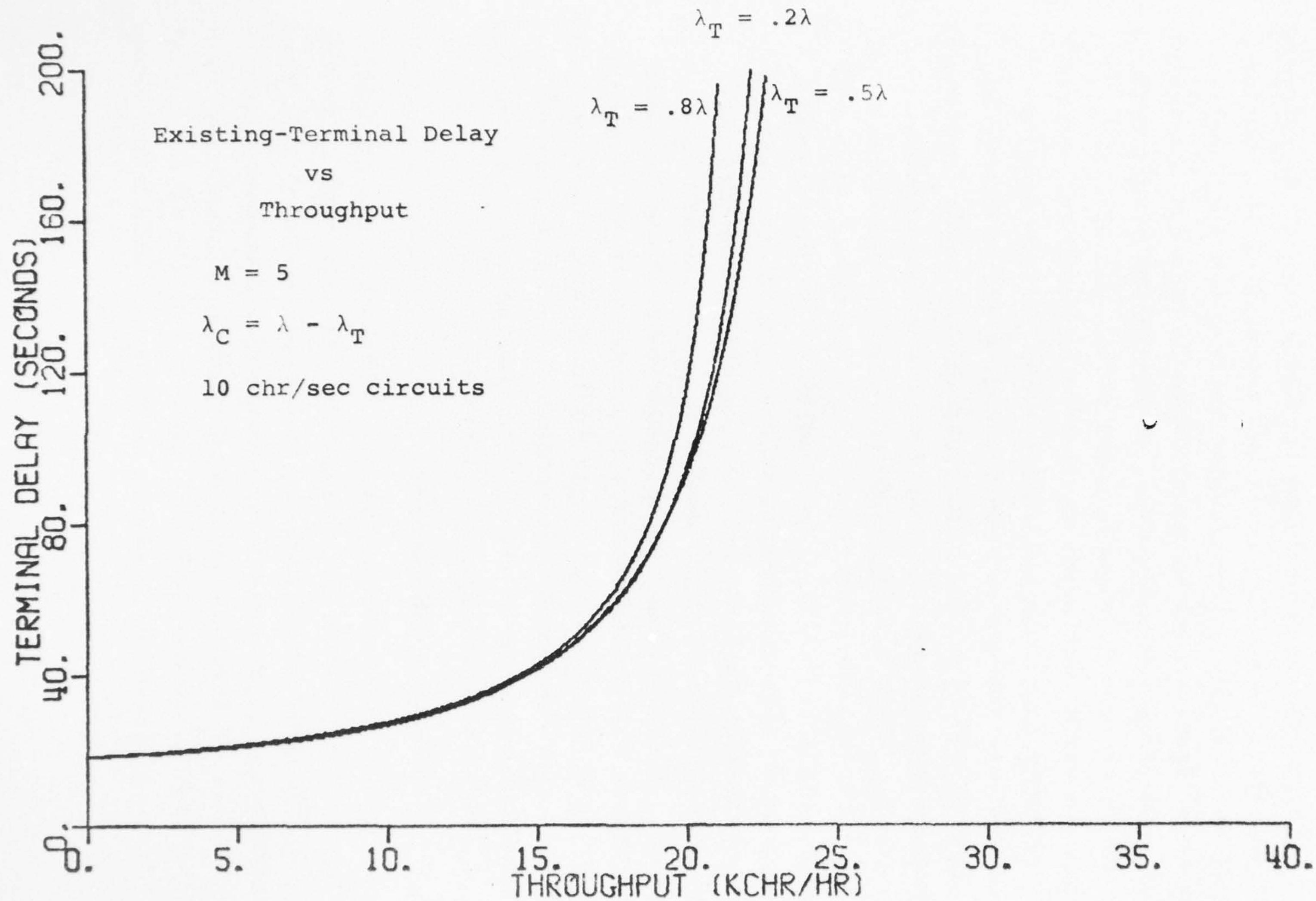


FIGURE D-6: EXISTING SERVICE B TERMINAL PERFORMANCE SENSITIVITY

a 50% increase in traffic starting at a high level will give much more severe queueing delay increases than a 50% increase starting at a low level. It is the rapidity of this latter change as a function of throughput which gives the appearance of a "knee" in the queueing curves. A design constraint based on performance analysis as presented above must reflect not only a reasonable average total delay, but also a reasonable margin for error in traffic projections. Since the traffic projections and analyses are already based on conservative estimates and assumptions, a reasonable design requirement for busy hour conditions is that a 25% increase in throughput should not more than double the total delay. A reasonable average total message delay from terminal to terminal through one concentrator is 90 seconds. With a five-terminal circuit ($M = 5$) these conditions are met with a throughput of approximately 16 KCHR/HR, having approximately a 45 second average delay on the terminal-to-concentrator link and approximately a 28 second delay on the terminal circuits. Since messages which originate on a circuit with M_1 terminals may be destined for a circuit with M_2 terminals, a worst case for M_2 has been used in developing the constraints. Using the above approach, the following simple formula gives a close approximation to the traffic constraints as a function of the number of terminals on a circuit:

$$\lambda \leq 19.0 - .6M \text{ KCHR/HR}$$

where λ is the total throughput (or traffic) of the circuit. With these constraints, Service B circuits will have an average delay of messages from terminals to concentrators of less than 60 seconds and an average delay of messages from concentrators to terminals of less than 30 seconds resulting in a total delay of less than 90 seconds. An increase in traffic of 25% beyond the level projected for 1984 will less than double these delays.

D.3.3 AFTN Circuits

The AFTN circuits differ from Service B in terms of the analysis presented in the previous section primarily in the timing components for polling. The AFTN polling procedures used in the region of AFTN operated by the FAA are a modified version of the Bell System 83B3 procedures as described in Appendix A. Based on the timing relations developed in the Bell System Technical Reference for the 83B3 procedures, the negative poll time, T_{NP}, and positive poll time, T_{PP}, are developed in Tables D-1 and D-2. The propagation times are based on the results of a Bell System study of teletypewriter circuits as reported in the above Technical Reference. The pauses reflect the time for the stunt boxes to respond. The time for a message to be delivered from the concentrator to the terminal is developed in Table D-3. Using these timing values plus the common message length distribution developed in Appendix C, the service times for the performance equations are:

$$\bar{X}_1 = 12.7 \text{ seconds}$$

$$\overline{X_1^2} = 234.1$$

$$\bar{X}_2 = .38M + 11.58 \text{ seconds}$$

$$\overline{X_2^2} = .2M^2 + 8.8M + 206.6$$

Using these values, a set of curves similar to those presented in the last section have been generated and are presented in Figures D-7, D-8, and D-9. The analysis of these curves is quite similar to that presented in the previous section. Note that the overall performance with the 83B3 procedures is considerably better than with the Service B procedures, as would be expected due to the shortening of the negative polling

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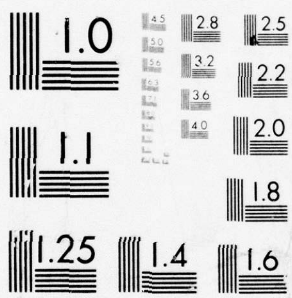


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Negative Poll

TSC Transmission	200.0 MSEC
Propagation Time	200.0 MSEC
Pause	59.5 MSEC
Negative Response (V)	100.0 MSEC
Propagation Time	200.0 MSEC
Conc. Proc. Time	1.0 MSEC
T_{NP} =	760.5 MSEC

TABLE D-1: AFTN NEGATIVE POLL TIME

Positive Poll

TSC Transmission	200.0 MSEC
Propagation Time	200.0 MSEC
Pause	59.5 MSEC
EOA Transmission	300.0 MSEC
Message Transmission	L X 100.0 MSEC
Propagation Time	200.0 MSEC
Processing Time	1.0 MSEC
T_{PP} =	L x 100.0 + 960.5 MSEC

TABLE D-2: AFTN POSITIVE POLL TIME

Concentrator Delivery

CDC Transmission	300.0 MSEC
Prop. Delay	200.0 MSEC
Pause	59.5 MSEC
V Answer back	100.0 MSEC
Prop. Delay	200.0 MSEC
Proc. Delay	1.0 MSEC
EOA Transmission	300.0 MSEC
Message Transmission	L * 100.0 MSEC
Prop Delay	200.0 MSEC

$$T_C = L * 100.0 + 1360.5 \text{ MSEC}$$

TABLE D-3: CONCENTRATOR DELIVERY TIME

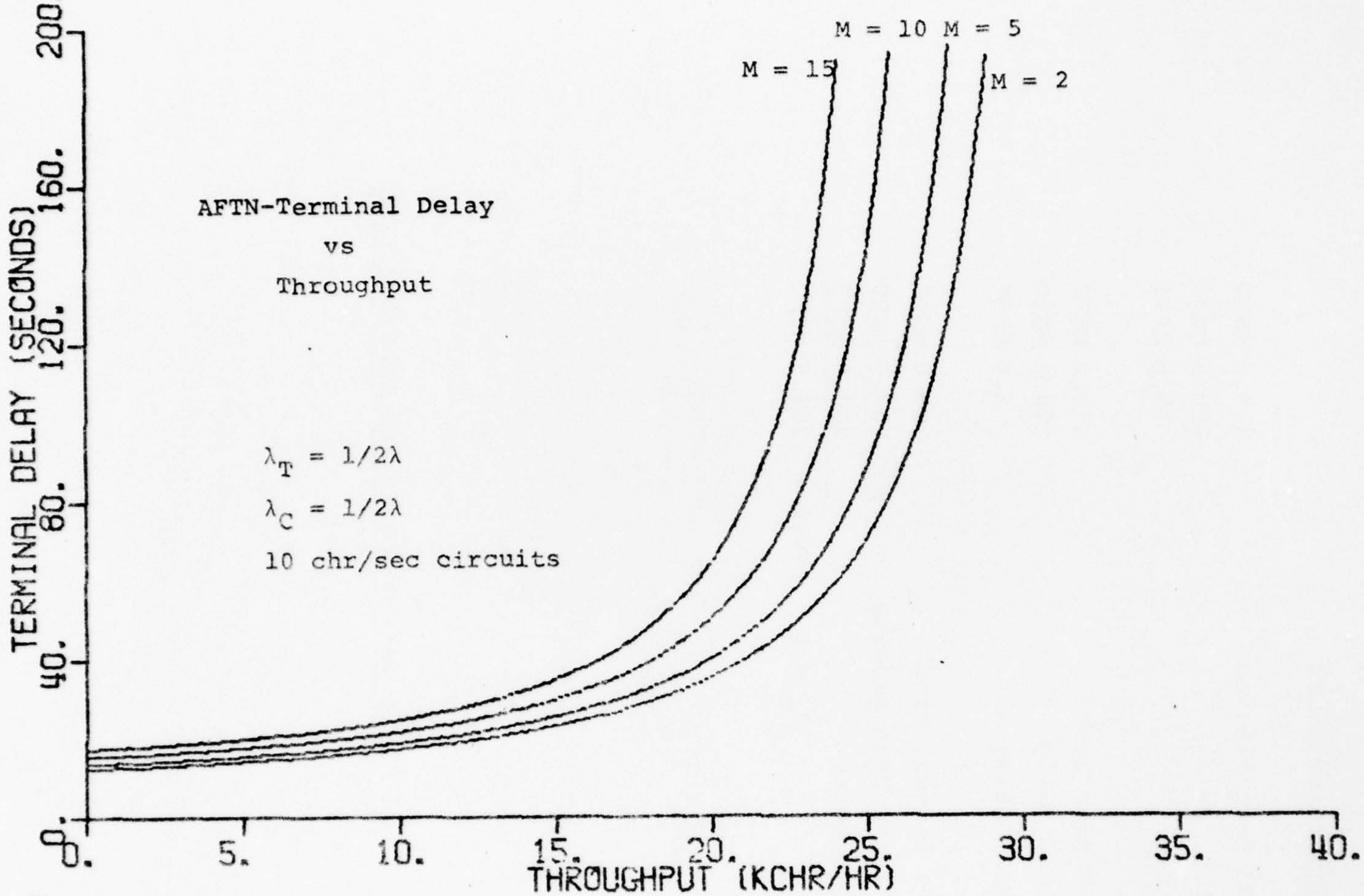


FIGURE D-7: AFTN TERMINAL PERFORMANCE

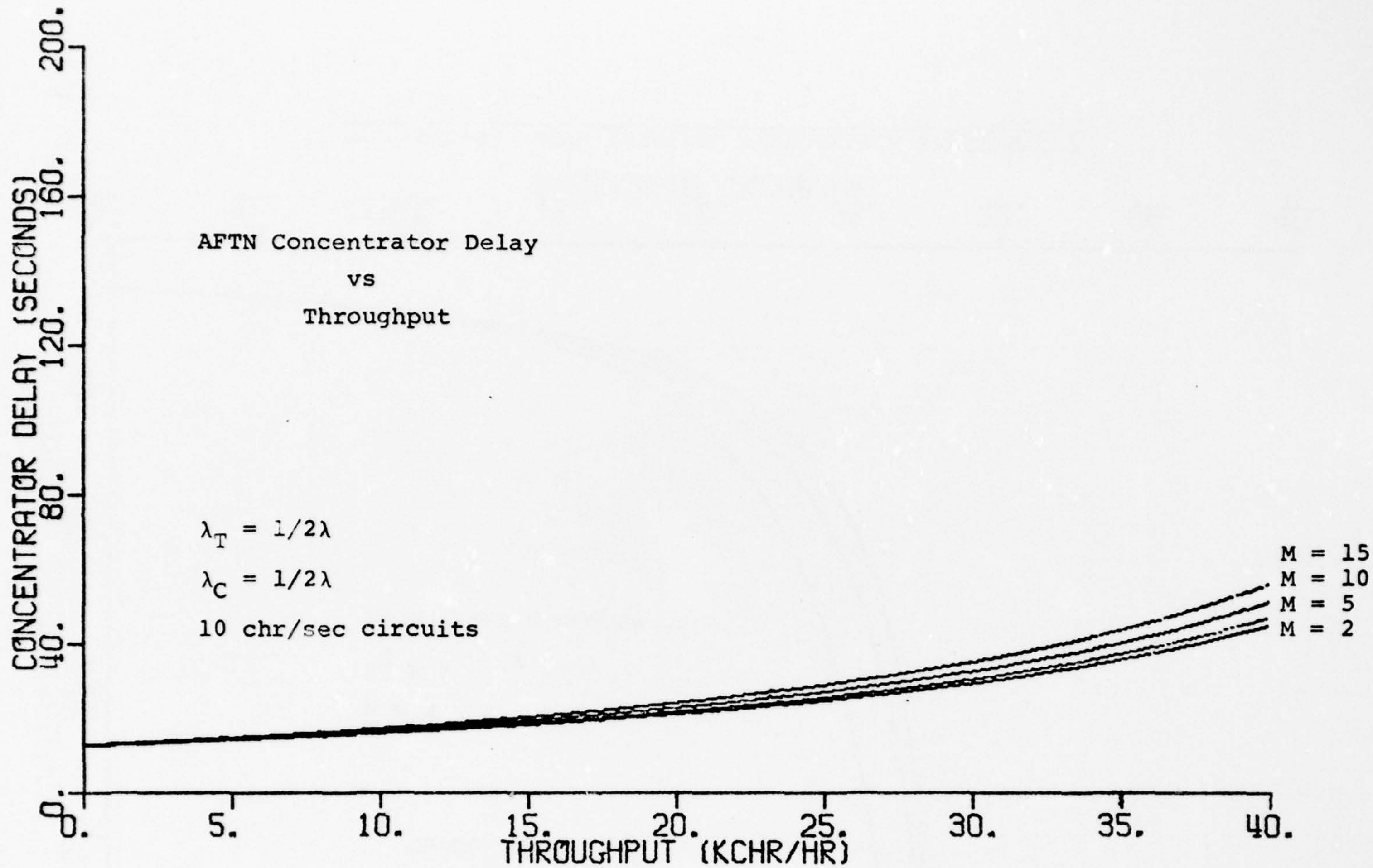


FIGURE D-8: AFTN CONCENTRATOR PERFORMANCE

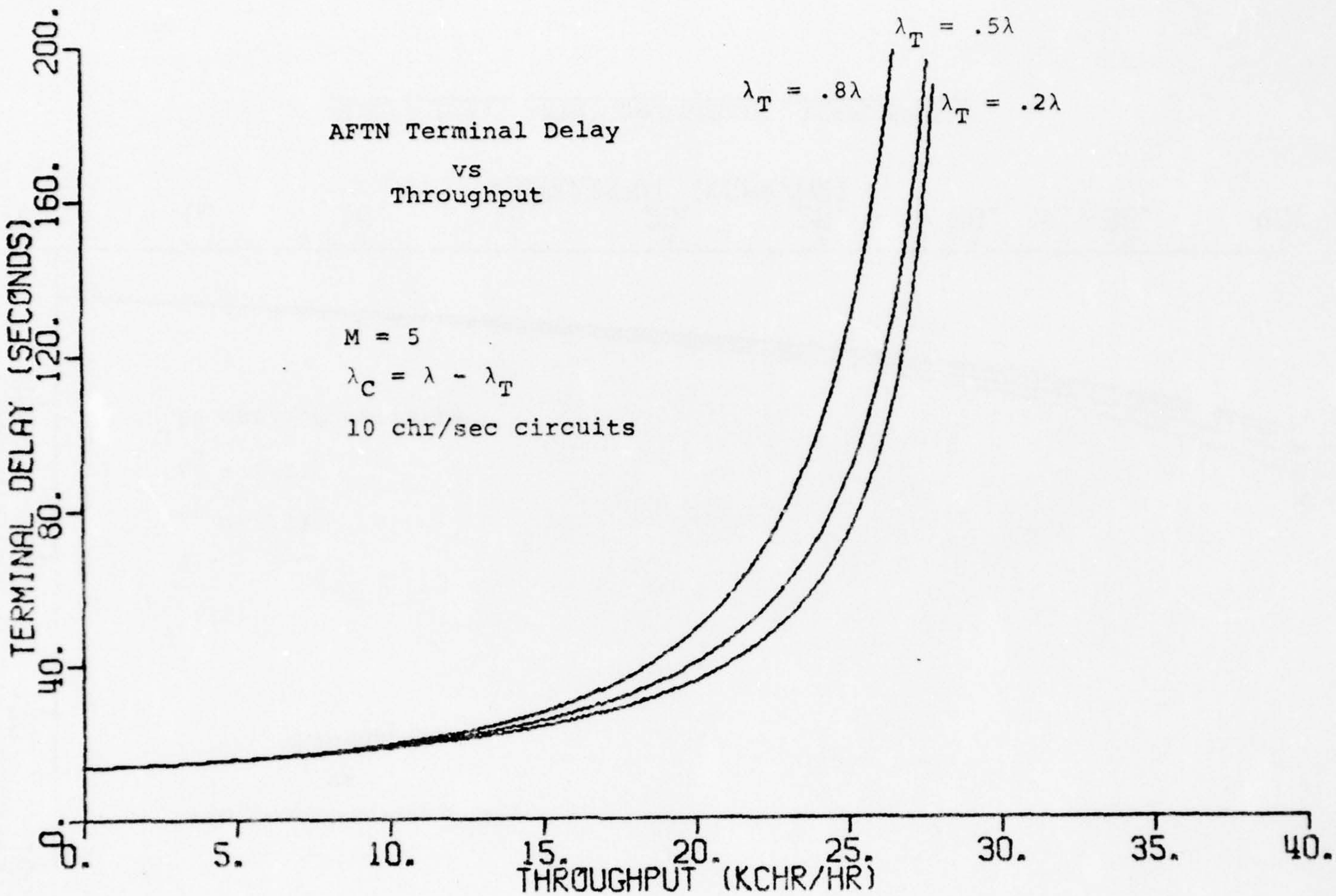


FIGURE D-9: AFTN TERMINAL PERFORMANCE SENSITIVITY

delays. The sensitivity to the traffic division is slightly greater, but still sufficently low as to validate the use of the even traffic division.

The same basic procedure for developing a design constraint as used in the previous section is appropriate here. Limiting an increase in total delay for a 25% increase in traffic to less than double the initial delay, and limiting the total delay (terminal to concentrator plus concentrator to terminal) to less than 90 seconds, the resulting design constraints can again be approximated by a simple formula as given below:

20.0 - .2M KCHR/HR .

For the M=5 case, this gives a maximum average delay of slightly less than 40 seconds for messages going from a terminal to a concentrator and a maximum average delay of approximately 20 seconds for messages going from a concentrator to a terminal.

D.3.4 NADIN Circuits

Medium speed terminals (1200 bps) using the IA #5 seven level code will be placed on voice grade circuits using a control procedure consistent with ANSI Standards X3.28-1971. The standards give functional definitions of six categories of "Establishment and Termination" control procedures, and five categories of "Message Transfer" control procedures, as shown in Table D-4. In addition, there are two categories of establishment and termination procedures and one message transfer category that are functionally defined and expected to be standardized in the near future. The basic form of a standard polling procedure is defined by specifying one of the establishment and termination categories and one of the message transfer categories. The ANSI procedures appear to be functionally divided into those appropriate for full duplex circuits and those appropriate for half duplex circuits.

TABLE D-4

ESTABLISHMENT AND TERMINATION SUBCATEGORIES

2.1	Two-Way Alternate; Switched Point-to-Point
2.2	Two-Way Alternate; Switched Point-to-Point with Identification
2.3	Two-Way Alternate; Nonswitched Point-to-Point
2.4	Two-Way Alternate; Nonswitched Multipoint with Centralized Operation
2.5	Two-Way Alternate; Nonswitched Multipoint with Centralized Operation and Fast Select
2.6	Two-Way Alternate; Nonswitched Multipoint with Noncentralized Operation

MESSAGE TRANSFER SUBCATEGORIES

A1	Message Oriented; without Replies and without Longitudinal Checking
A2	Message Oriented; without Replies and with Longitudinal Checking
A3	Message Oriented; with Replies and without Longitudinal Checking
B1	Message Associated Blocking; with Longitudinal Checking and Single Acknowledgements
B2	Message Associated Blocking; with Longitudinal Checking and Alternating Acknowledgements

FUTURE ESTABLISHMENT AND TERMINATION SUBCATEGORIES

X2.7	Two-Way Alternate; Nonswitched Multipoint with Centralized Operation and Multiple Slave Transmission
X2.8	Two-Way Alternate; Nonswitched Multipoint with Noncentralized Operation and Multiple Slave Transmission

FUTURE MESSAGE TRANSFER SUBCATEGORIES

XC1 Message Independent Blocking; Noncontinuous Operation with Longitudinal Checking and Alternating Acknowledgements

D.3.4.1 Circuit Types

Full duplex circuits may be considered to be organized as in Figure D-10. In this case, all terminals can hear the concentrator and the concentrator can hear all terminals; however, no terminal hears another terminal directly. Half duplex circuits may be considered to be organized as in Figure D-11. In this case, all terminals and the concentrator hear the transmissions of all other terminals and the concentrator. One of the differences between the two circuit organizations is that with full duplex the concentrator can transmit a message at the same time a terminal is transmitting, but all terminal-to-terminal intra-circuit messages must pass through the switching concentrator; whereas with half duplex, only one device, either concentrator or terminal, can transmit at a time, but messages may be delivered directly between terminals without passing through the concentrator.

Selection of the best of the alternative procedures for use with the medium speed NADIN terminals requires considerable study, and such study is currently underway. However, for the purposes of this report, it is sufficient to select a reasonable candidate such as 2.6 - A2, a procedure appropriate for half duplex circuits. Flow charts for this procedure are shown in Figures D-12 and D-13. In the analysis which follows, circuits have a nominal capacity of C = 1200 bps. The terminals all operate in a 10 unit code composed of 7 information bits, 1 parity bit, 1 start bit, and 1 stop bit. Thus, a character requires 8.333 milliseconds for transmission.

In large part, the circuits used by the FAA may be expected to be basic voice grade Bell System circuits (3002 designation). In general, the circuits may be either two-wire or four-wire, and operated in either a half duplex

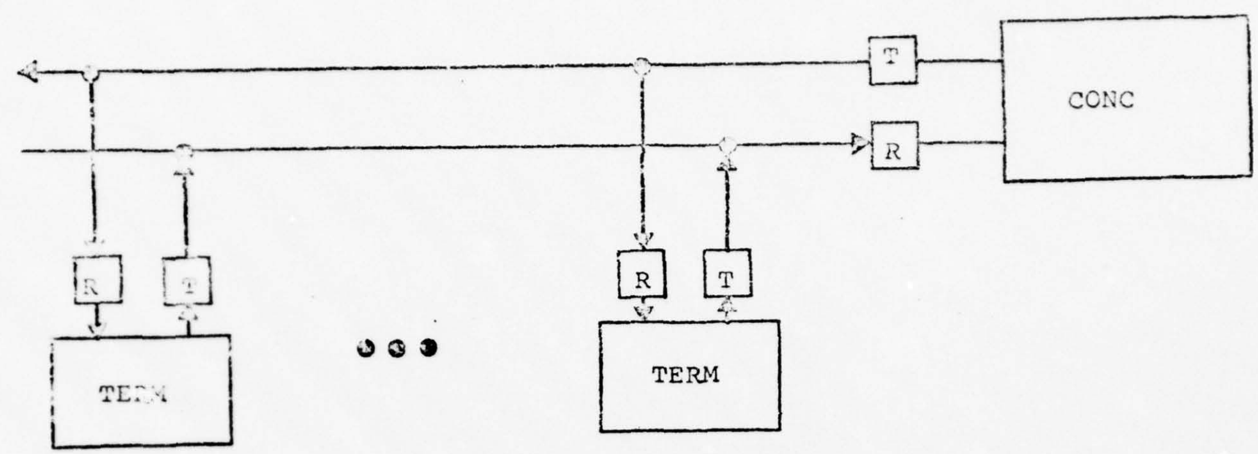


FIGURE D-10: FULL DUPLEX ORGANIZATION

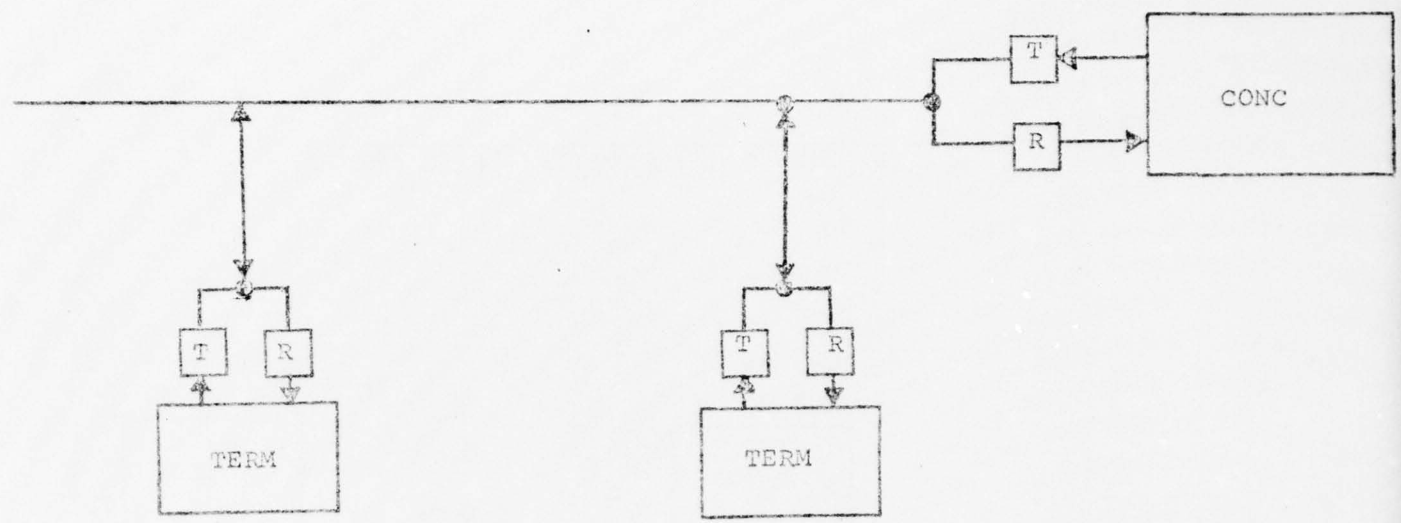
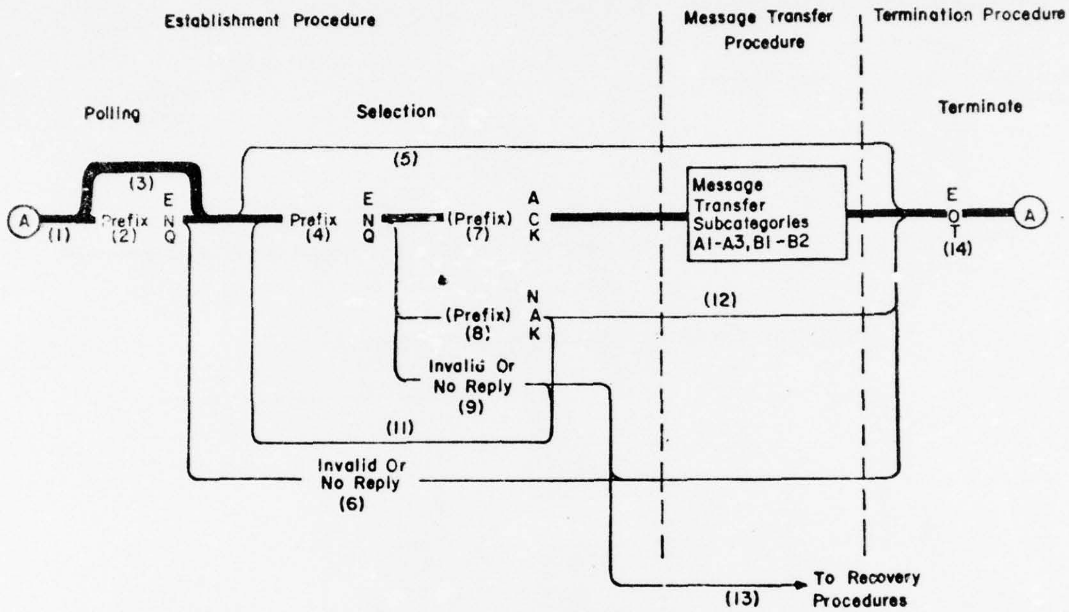
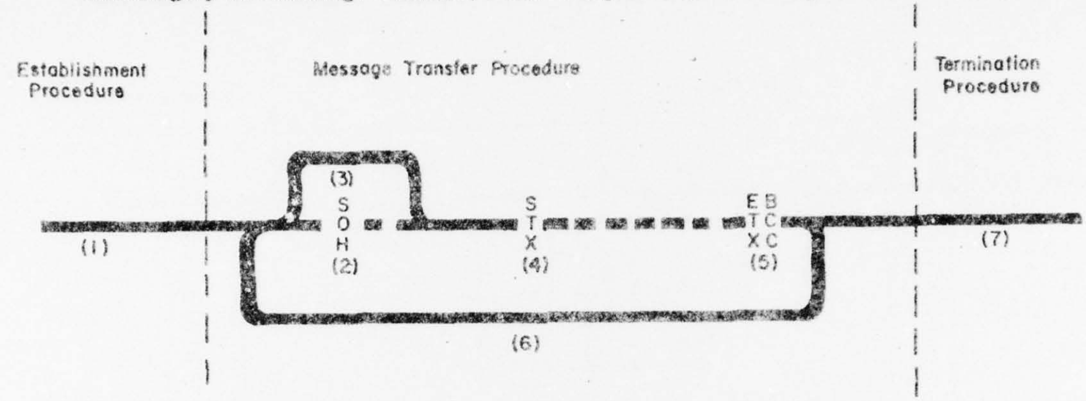


FIGURE D-11: HALF DUPLEX ORGANIZATION

Subcategory 2.6: Two-Way Alternate; Nonswitched Multipoint with Noncentralized Operation



Subcategory A2: Message Oriented; without Replies and with Longitudinal Checking



or full duplex mode. The Bell System recommends (Tech Ref. PUB 41004) that in multipoint circuits with more than six stations, four-wire circuits be used for both half duplex and full duplex operation. In the FAA today, virtually all circuits are four-wire, half duplex. In this analysis, only four-wire circuits will be considered.

The Bell System will not specify a nominal propagation delay for the 3002 channel, due to extreme variations depending on a number of physical attributes of the circuits. The specified maximum of 50 ms appears to be excessive; however, an estimate of 20 ms as a nominal value appears reasonable. It is this latter value that will be used in the following analysis.

D.3.4.2 Modem Operation

Data is transferred over the channel through the use of modems. Most modems for a 1200 bps data rate employ an asynchronous, FSK transmission scheme and are controlled through the EIA RS-232 standard interface. The interface signals are listed in Figure D-14. Of particular significance in a dedicated, multipoint polled operation is the sequence of signals shown in Figure D-15. This sequence occurs when a terminal responds to a polling request. The terminal (DT_1) must first alert its modem (DS_1) that it intends to send data (CA_1 true-request to send). The modem starts transmission of the carrier (T) and, after a preset delay, tells the terminal it is ready (CB_1 true-clear to send). Prior to this event, the modem at the other end (DS_2) should have detected the carrier and announced to the central (DT_2) that transmission was being received (CF true-received line signal detector). Upon receipt of the clear-to-send signal, the originating terminal (DT_1) supplies its modem (DS_1) with data (BA_1 - Transmitted Data). The data is sent in an FSK mode (T) and detected by the modem at the other end (DS_2).

Interchange Circuit	C.C.I.T.T. Equivalent	Description	Gnd	Data		Control		Timing	
				From DCE	To DCE	From DCE	To DCE	From DCE	To DCE
AA	101	Protective Ground	X						
AB	102	Signal Ground/Common Return	X						
BA	103	Transmitted Data			X				
BB	104	Received Data		X					
CA	105	Request to Send					X		
CB	106	Clear to Send				X			
CC	107	Data Set Ready				X			
CD	108.2	Data Terminal Ready					X		
CE	125	Ring Indicator				X			
CF	109	Received Line Signal Detector				X			
CG	110	Signal Quality Detector				X			
CH	111	Data Signal Rate Selector (DTE)					X		
CI	112	Data Signal Rate Selector (DCE)				X			
DA	113	Transmitter Signal Element Timing (DTE)							X
DB	114	Transmitter Signal Element Timing (DCE)						X	
DD	115	Receiver Signal Element Timing (DCE)						X	
SBA	118	Secondary Transmitted Data			X				
SBB	119	Secondary Received Data		X					
SCA	122	Secondary Request to Send					X		
SCB	121	Secondary Clear to Send				X			
SCF	122	Secondary Rec'd Line Signal Detector				X			

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FIGURE D-14: MODEM INTERFACE SIGNALS

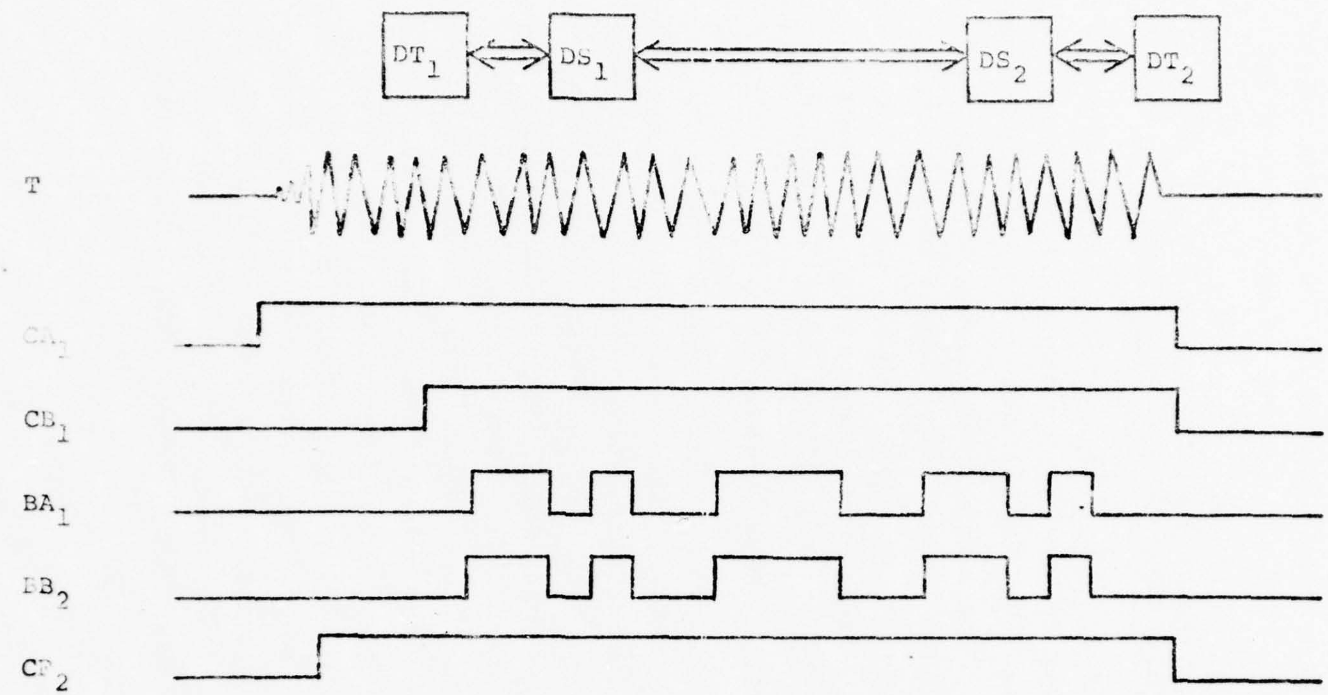


FIGURE D-15: MODEM CONTROL SIGNALS

This modem transfers the data in digital form to the central (BB_2 - Received Data). After the originating terminal (DT_1) has completed its transfer of data, it removes the request-to-send (CA_1 - False). The carrier (T) is then removed and clear-to-send is cancelled (CB_1 - False). At the other end, the modem (DS_2) indicates the termination of carrier (CF_2 - False) and clamps the received data (BB_2).

In order for the above sequence to occur, it is necessary that both the modems and terminals be in a "ready" condition, indicated by the signals CC (Data Set Ready) and CD (Data Terminal Read) both being true. These signals imply power is on and the units are operational, which is the normal case in the FAA operation. In the initial investigation, these signals will be assumed always true. Performance during the exceptional cases will be considered later.

D.3.4.3 Basic Timing Relationships

In the control signals described above, the longest delay element is the CA-CB (request-to-send - clear-to-send) response time. This delay depends on the particular modem design and options selected on the basis of circuit characteristics. For a four-wire, multipoint circuit (without talk-back bridges), the Bell System 202R is nominally set for a 60 msec delay, but can be optionally set for a 20 msec delay if fast turnaround is required. The Collins TE-1200 is nominally set at 8 msec. Other modems may have different delays. For this study, all timing considerations will be based on Bell System 202R modems, as they appear rather conservative in performance, are well documented, and are possible choices for actual FAA use. The impact of modems with less delay (including use of own timing versus CA-CB) will be evaluated later.

In addition to the CA-CB, other delays are present in the modems. For a 202R modem, the carrier turn-off delay (with "quick" option) is 7 milliseconds, and the received line signal detector time delay (termination of carrier to CF - False) is nominally 15 milliseconds.

In the half-duplex (HDX) case, only one unit (terminal or central) can transmit at a time. In this section, we can consider the timing involved for a transmission of a block and return of circuit to ready status, i.e., the time from originating station making request-to-send true until the time when the next station may be permitted to make request-to-send true. This timing is detailed in Figure D-16 and Table D-5, and is found to be, for a block of N characters,

$$TB_{HDX} = N \times 8.33 + 72 \text{ milliseconds}$$

Three basic operations of positive poll, negative poll, and concentrator delivery of a message may be viewed as composed of the following basic events:

1. Polling message
2. Negative response message
3. Select inquiry
4. Positive select response
5. Negative select response
6. Message delivery

Event 5 can be disregarded in this analysis.

The time for the three basic operations can now be formulated in terms of the above events:

$$T_{NP} = T_1 + T_2$$

$$T_{PP} = T_1 + T_3 + T_4 + T_6$$

$$T_C = T_3 + T_4 + T_6$$

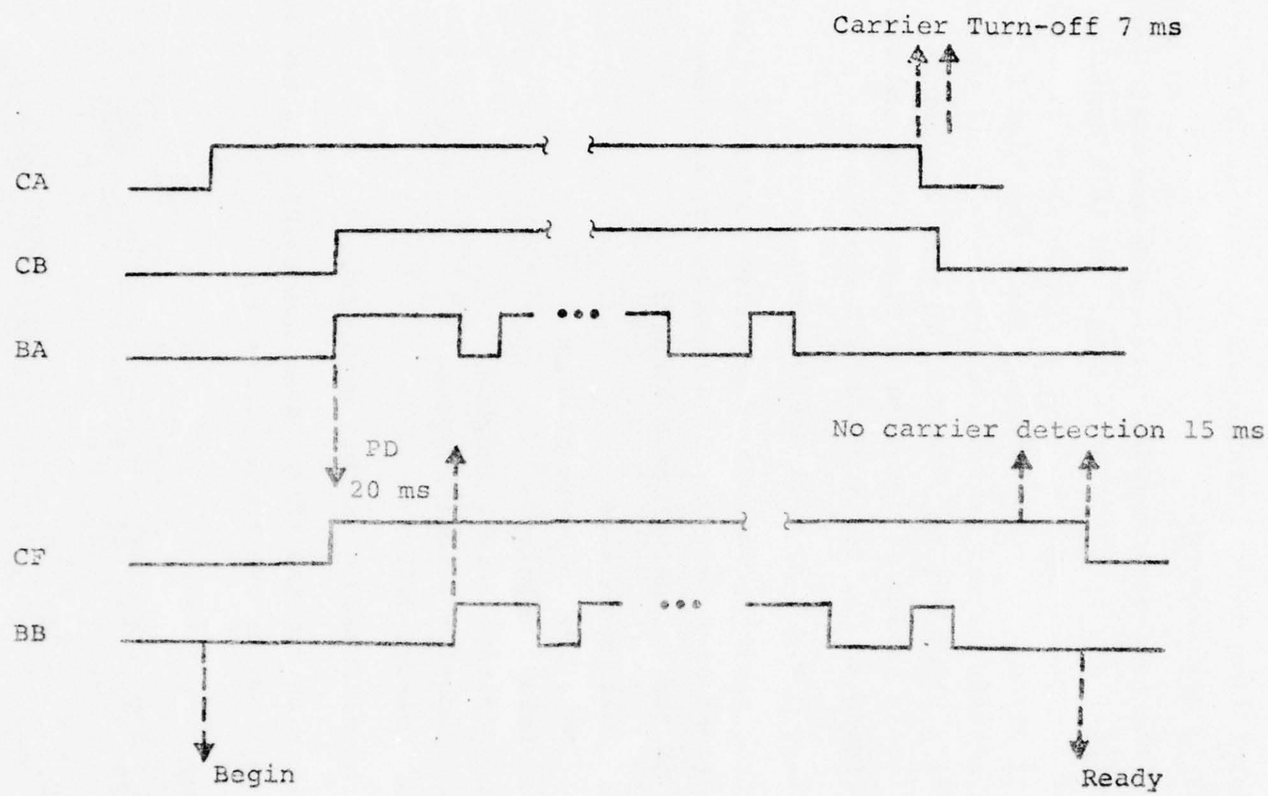


FIGURE D-16: MODEM CONTROL TIMING

CA	True	initiate request	
CB	True	clear to send	30 ms
Propagation delay			20 ms
Carrier turnoff			7 ms
No carrier Detection (CF return to false)			15 ms
N characters			NX 8.33 ms

$$TB_{HDX} = N \times 8.33 + 72 \text{ ms}$$

TABLE D-5: HALF-DUPLEX TIMING

Each of the events used in the above timing relations is a basic TB_{HDX} operation (transmission of a message of N characters), differing only in the number of characters being transmitted.

D.3.4.4 Delay Analysis

In order to define these timing relationships precisely, it is necessary to determine the number of characters used in the various operations. There are no established 7-unit code formats for AFTN messages, but the FAA has proposed one for AFTN (See Attachment 1), which will be used in this analysis. A NADIN format is proposed in Appendix G; this or other formats and variations can be easily incorporated in the analysis at a later date.

Based on the format given in Attachment 1, the message length L is composed of the following:

$$\text{Header:}\quad \begin{matrix}S\\O\\H\end{matrix}\ A,\ A_2\ A_3\ N,\ N_2\ N_3 < < \equiv$$

$$A_4\ A_5 \rightarrow A_6\ A_7\ A_8\ A_9\ A_{10}\ A_{11} < \equiv$$

$$D\ D\ H\ H\ M\ M \rightarrow A_{12}\ A_{13}\ A_{14}\ A_{15}\ A_{16}\ A_{17} < \equiv$$

$$\text{Text:}\quad \begin{matrix}S\\T\\X\end{matrix}\ \text{(TEXT)}\ \begin{matrix}V\\T\end{matrix}$$

$$\text{Ending:}\quad \begin{matrix}E & B & E\\T & C & O\\X & C & T\end{matrix}$$

The notation is explained in Table A-1, except for the ANSI control characters, which are explained in Attachment 1.

Note that an EOT character has been added to the end as part of the ANSI termination procedures and the BCC character has been added as the error control character part of message transfer sub-category A2. This gives an overhead component of 41 characters, conveniently consistent with the

general biased exponential distribution of the message length distribution developed in Appendix C.

A polling message requires a terminal identification code, identification of polling operation, and ENQ character. Assuming a single character is sufficient for station identification, the polling message requires a three character transmission. The negative polling response is simply an EOT character. Thus, the negative polling time is simply:

$$T_{NP} = 4 \times 8.33 + 2 \times 72 \text{ ms, or}$$

$$T_{NP} = 177 \text{ ms}$$

The select inquiry operation also requires a three-character code (station identification, select designation, and ENQ). A positive selection acknowledgement can be a single character, ACK, or a two-character code identifying selected station, I ACK. The latter will be assumed for error control. The positive poll timing is then:

$$\begin{aligned} T_{PP} &= (3 \times 8.33 + 72) + (3 \times 8.33 + 72) \\ &\quad + (2 \times 8.33 + 72) + (L \times 8.33 + 72) \\ &= 355 + L \times 8.33 \text{ ms} \end{aligned}$$

The concentrator delivery time is:

$$\begin{aligned} T_C &= (3 \times 8.33 + 72) + (2 \times 8.33 + 72) \\ &\quad + (L \times 8.33 + 72) \\ &= 258 + L \times 8.33 \text{ ms} \end{aligned}$$

Using the message length distribution of Appendix C, this gives:

$$T_{NP} = .177 \text{ sec.}$$

$$T_{PP} = 1.271 \text{ sec.}$$

$$T_C = 1.174 \text{ sec.}$$

These values are then used in the basic service time formulae developed earlier to give:

$$\bar{X}_1 = 1.26 \text{ seconds}$$

$$\overline{X_1^2} = 2.10$$

$$\bar{X}_2 = .09M + 1.18 \text{ seconds}$$

$$\overline{X_2^2} = .01M^2 + .21M + 1.82$$

Delay versus throughput curves using these values have been generated, and are shown in Figures D-17, D-18, and D-19. These curves have the same basic form as those produced in the previous sections. However, note that both axes have been scaled by an order of magnitude, reflecting the fact that voice grade circuits, in comparison with low speed circuits, provide an order of magnitude increase in throughput along with an order of magnitude reduction in delay. Thus, although the same basic observations can be made about these curves as was made about the earlier curves, the quantitative aspects of the analysis are different. In particular, the average total delay of a message over the terminal circuits (terminal-to-concentrator plus concentrator-to-terminal) should be no more than eight seconds (instead of 90 as for the low speed case). As before, a 25% increase in throughput over the nominal design value should no more than double the total delay. For the M = 5 curve, this occurs with a throughput of approximately 180 KCHR/HR, having approximately a 4 second average delay on the terminal-to-concentrator link and approximately a 2 second average delay on the concentrator-to-terminal link.

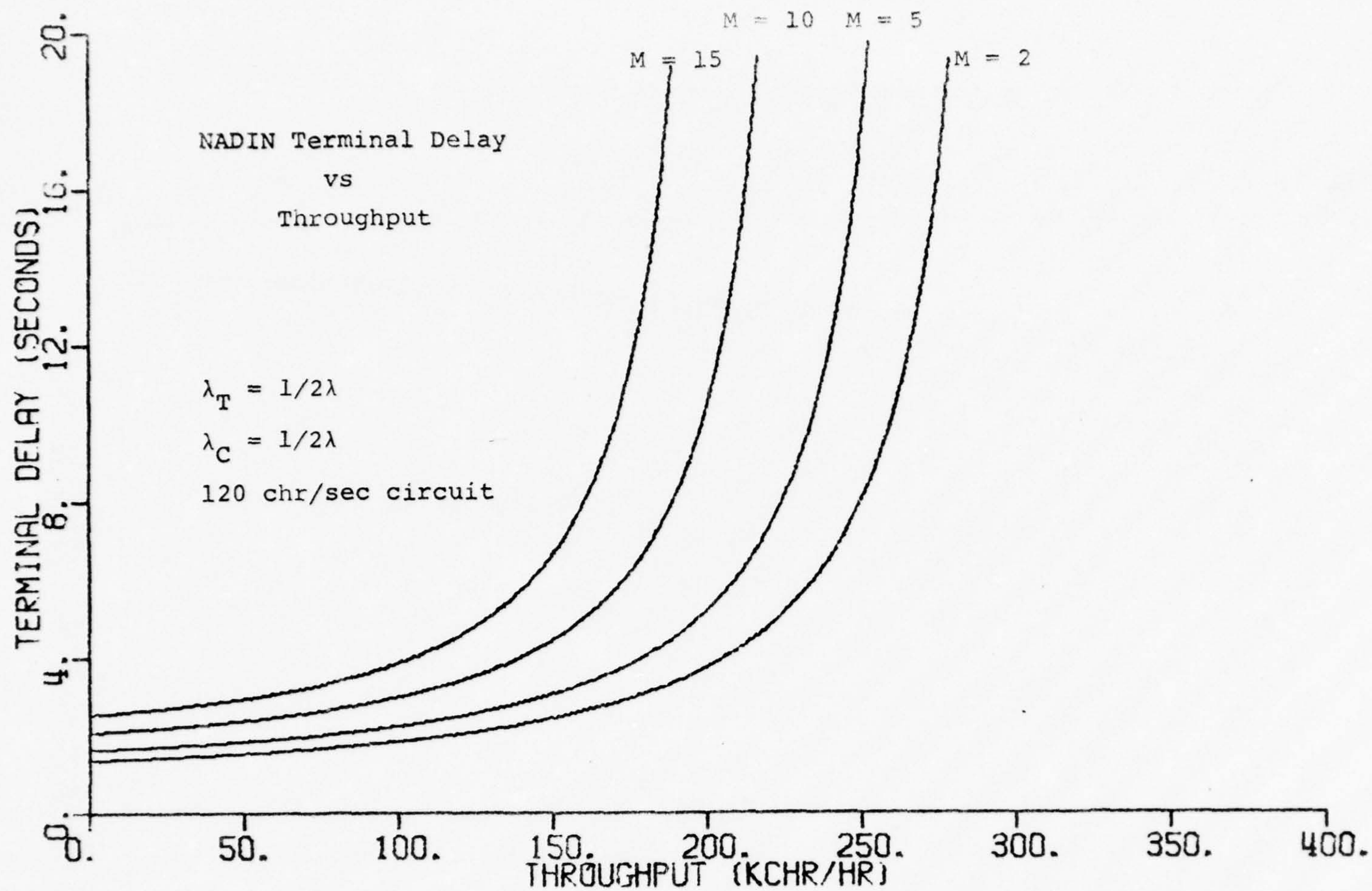


FIGURE D-17: NADIN TERMINAL PERFORMANCE

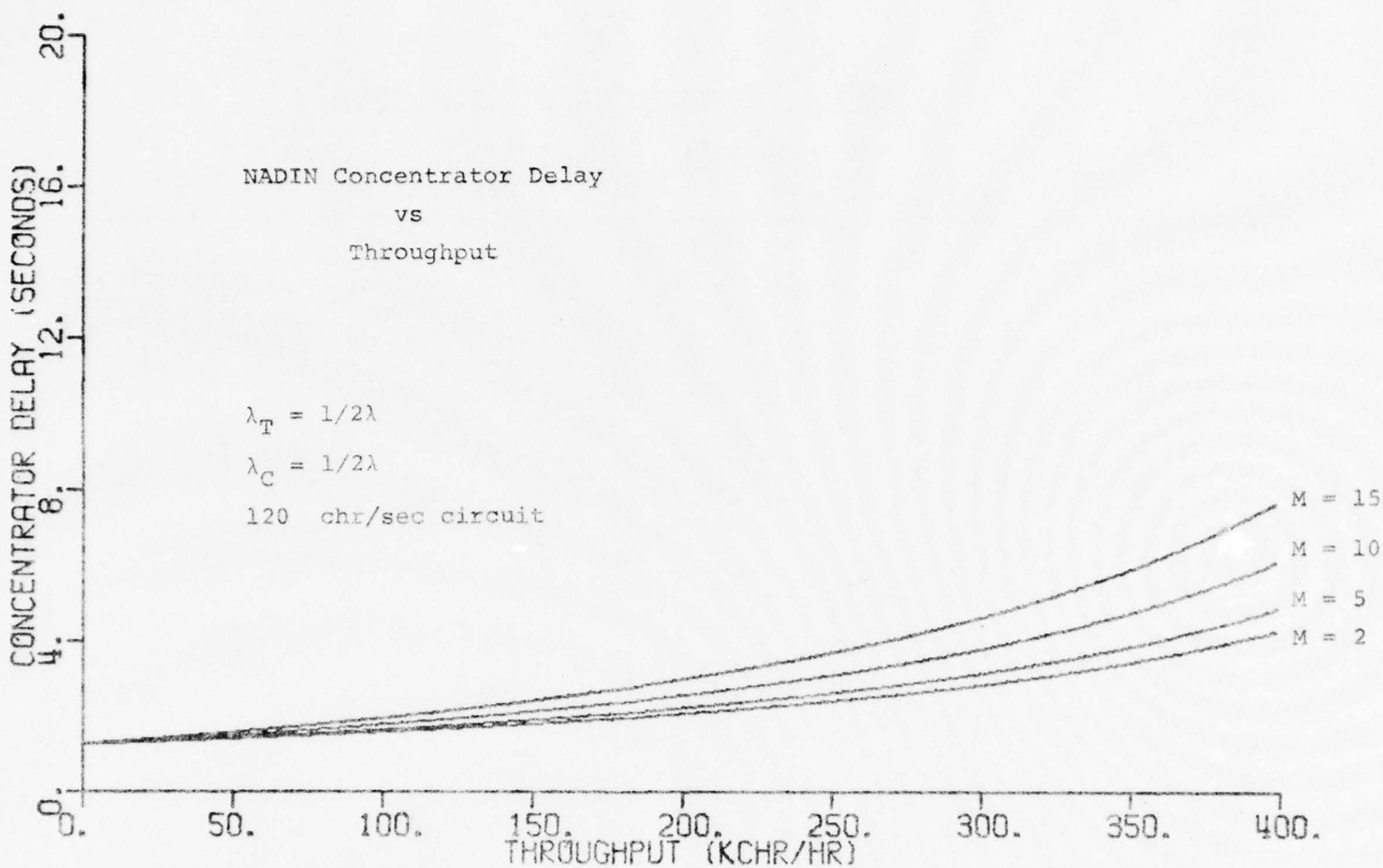


FIGURE D-18: NADIN CONCENTRATOR PERFORMANCE

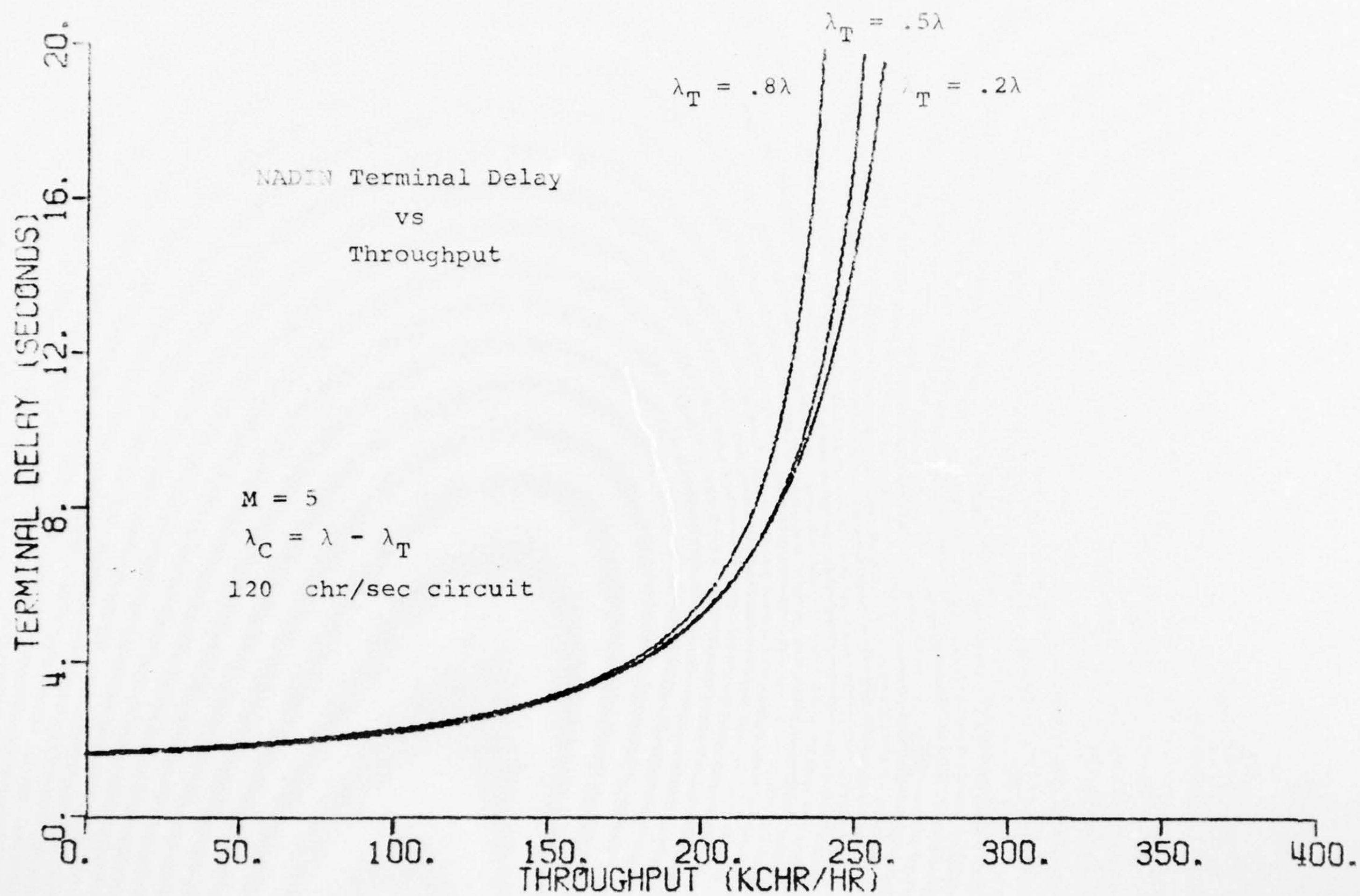


FIGURE D-19: NADIN TERMINAL PERFORMANCE SENSITIVITY

Using the same basic procedure for constraint development as described earlier, the linear constraint approximation is;

210 - 6M KCHR/HR

D.4 CONCENTRATOR - SWITCH CIRCUITS

The circuits connecting concentrators to switches will be leased four-wire voice grade facilities having the basic characteristics as described in Section D.3.4.2. Modems can be obtained to operate these circuits at the nominal rates of 1200, 1800, 2400, 3600, 4800, 7200, and 9600 bps. The appropriate rates will depend on traffic to be supported by the circuits . The circuits will be operated in a full duplex mode using the control procedures defined in the ADISP/4 Report for a balanced point-to-point configuration. These procedures are similar to the ANSI Advanced Data Communication Control Procedures (ADCCP), and are based on a synchronous communications scheme incorporating a basic frame structure as outlined below:

F A C text FCS F

where

F - is an eight bit delimiter (01111110) called a flag. It is a unique pattern of bits that is prevented from appearance elsewhere by inserting a zero after any sequence of five one's at the transmitting end and deleting the corresponding zero at the receiving end;

A - is an eight bit address field;

C - is an eight bit control field; and

FCS - is a sixteen bit polynomial error checking code sequence.

In this procedure, the text is transparent, i.e., there are no restrictions on the text code. The text transparency permits efficient coding of information and allows future alterations in information structure to take place without affecting the communications environment.

The protocol distinguishes a primary station as the one which originates commands. In order for each of two stations to be able to originate message transmissions, a Primary/Primary configuration is defined (balanced point-to-point), as shown in Figure D.20. At station A, messages to be sent to station B are transmitted via the station A primary to the station B secondary. The station B secondary responses (i.e., acknowledgements) are then returned to the station A primary. Similarly, messages to be sent from station B to station A are transmitted via the station B primary to the station A secondary. This division permits an easy accounting of sequence numbers and secondary state variables. Note that a full duplex modem interface at each station suggests two software function modules, Line Control Out for transmission and Line Control In for reception. Responses carrying the secondary's own address allow the Line Control In modules to determine to which module (primary or secondary) an arriving frame is to be transferred.

The 16 bit polynomial code provides a means of identifying a frame with a transmission error. To correct an error, it is necessary to retransmit the frame. Acknowledgements must be returned to the sender of the frame to identify which frames are to be retransmitted. If each new frame must wait for the previous frame to be acknowledged before it is transmitted, the procedure is called stop and wait automatic repeat request (S&W ARQ). If frames are continuously transmitted without waiting for acknowledgements, but when negative acknowledgements occur the negatively acknowledged frame and

all subsequently transmitted frames are retransmitted, the procedure is called continuous ARQ. On full duplex facilities, the continuous ARQ is substantially more efficient than S&W ARQ and will be used in this analysis.

The performance of the continuous ARQ procedure is described in terms of the effective line speed (versus the nominal line speed) given by:

$$S_E \geq S\left(\frac{1 - P(n)}{1 + X\ P(n)}\right)$$

where:

S_E - is the effective line speed,

S - is the nominal line speed,

$P(n)$ - is the probability that a frame of n bits has an error and thus must be retransmitted,

X - is the minimum number of frames for retransmission.

The average frame size is given by the sum of the frame overhead, 48 bits, (second flag must be received to identify end of frame) and the message, 110 characters. Assuming eight bits per character (allowing all messages to be in ITA #5 code), this gives a frame size of 928 bits. Based on the Bell System Technical Reference PUB 41007 (1969-70 Switched Telecommunications Network Connection Survey) leased circuits should be obtainable with a frame error rate of less than 10^{-2}. Thus:

$$P(928) = .01$$

The value of X is given by:

$$X = \left\lceil \frac{S \cdot t_R}{n} \right\rceil$$

where:

$\lfloor y \rfloor$ - signifies the smallest integer greater than or equal to any given value y;

t_R - is the maximum length of time within which an "accept-no accept" response is expected from the receiving station after the last bit of the frame has been transmitted; and

n - is the average number of bits per frame (928).

The value of t_R can be found from the relation:

$$t_R = .1 + \frac{n}{S} + \frac{40}{S} \text{ seconds}$$

where:

.1 - second is the sum of the propagation delay and processing time for the frame;

$\frac{n}{S}$ - is the approximate maximum queueing time for the response (with responses given non-preemptive priority for the channel over message transmission); and

$\frac{40}{S}$ - is the transmission time of the response (only one flag needed since no text).

Using these values, the effective line speeds for the range of nominal speeds listed earlier are all approximately 3% less than the nominal values. This result can now be used to appraise the total delays in message transfer from a concentrator to a switch and from a switch to a concentrator. Note that by symmetry, these two delays will have the same average.

A single-server queueing model is again appropriate for the system, with Poisson arrivals and a biased exponential service time. The biased exponential is now composed of an overhead constant consisting of the previous 40 characters for the message plus a frame overhead of 48 bits resulting in

an average total message length of 928 bits with a constant component of 368 bits (assuming eight-bit characters). The message length distribution now has a coefficient of variation equal to .36. For conservative analysis, a coefficient of variation of .60 will be used. The total time required for message transfer may be expressed with the aid of the Polloczek-Khintchine formula as:

$$T_{CS} = \frac{1}{\lambda}\left[\zeta + \frac{\zeta^2(1+C^2)}{2(1-\zeta)}\right]$$

where:

- $\bar{X}$ - is the average service time of a message (sec/msg);
- ζ - $\lambda\bar{X}$ is the circuit utilization:
- C^2 - is the coefficient of variation.

The average service time of a message, $\bar{X}$, is simply the message length, in bits, divided by the effective line rate, in bits per second, or:

$$\bar{X} = \frac{928}{S_E}$$

Using this result, the delay versus throughput curves for the nominal line speeds listed earlier are shown in Figure D-21. In these curves, the throughput is in millions of message characters per hour, i.e., the throughput only includes the characters in the text portion of the frames, not the control frames nor the overhead bits in a message frame.

The curves shown in Figure D-21 are quite similar in form to those presented in the previous section. In order to design the NADIN properly, it is necessary to select a line speed for the concentrator-to-switch circuit which will ensure both reasonable delay and reasonable insensitivity to error in traffic estimates. Thus, as before, with a requirement

that a 25% increase in traffic less than double the total delay, appropriate line speeds can be determined as a function of the required throughput. Based on the results presented above, Table D-6 has been generated showing appropriate line speeds as a function of the throughput requirements. Also shown are the maximum delays which may result from such selections. Note that in all cases the delay is less than one second.

D.5 SWITCH - SWITCH CIRCUITS

The circuits interconnecting switches will be leased four-wire, voice-grade facilities having the basic characteristics as described in Section D.3.4. The circuits will be operated in a full duplex mode using the same basic control procedure described in the previous section for the exchange of information. However, as part of the NADIN concept, the switches are to be part of the Common ICAO Data Interchange Network (CIDIN). As part of CIDIN, the switch operation will have to be consistent with the functional specifications for CIDIN being developed by the ADIS Panel of ICAO. The impact of these specifications on NADIN are currently being investigated in detail. However, for the purposes of this report, it is sufficient to note that as part of these specifications, an additional overhead will occur in the frame structure used in transferring information between the switches. The basic frame structure as described in the ADISP/5 Report is:

DLCF CCF CDF DLCF

where DLCF (Data Link Control Field) is the basic flag, control, address, and frame check sequence fields used for frame transfer over the circuitry as described for the ADCCP procedures in the previous section; CCF (Communications Control Field) is the additional information to permit routing of messages

through multiple switches; and CDF (Communications Data Field) is the actual message being sent. The CCF is the part which contributes additional overhead compared to that of the basic procedure of the previous section.

The CCF includes all information required to implement the network control procedures specified for CIDIN. It is composed of indicators used to identify:

- Entry and exit switching center addresses,
- Message type and priority,
- Message and frame numbers,
- Message code and format,
- Network error control information.

The CCF is generated by the initial switching center receiving the message (entry SC) and is interpreted by each SC which must relay the message or direct it to one of its terminals or concentrators. The basic format of the CCF is shown in Figure D-22 and interpreted in Table D-7, both taken from the ADISP/5 Report. As can be seen, the basic overhead increase is an additional 40 bits per frame. This gives a less than 5% increase in the overall average frame size for NADIN messages as compared to the basic size developed in the previous section. This is well within the design tolerances used in developing Table D-5 and thus this table is also used to specify the required capacities for switch-to-switch circuits as a function of the throughput.

D.6 NADIN PERFORMANCE

In the previous sections, the components of NADIN operation that determine the traversal time of a message from its origin to its destination have been analyzed. Constraints to ensure reasonably conservative designs were developed on the basis of equipment characteristics and as a function of the

traffic. The performance of a NADIN network designed consistent with these constraints can be summarized by the following values for the average component times contributing to the traversal time:

T_{TC}

(Terminal-to-Concentrator)

	Service B, AFTN	$\leq$ 50 sec.
	Voice Grade NADIN	$\leq$ 5 sec.

T_{CT}

(Concentrator-to-Terminal)

	Service B, AFTN	$\leq$ 30 sec.
	Voice Grade NADIN	$\leq$ 3 sec.

T_{CS}, T_{SC}

(Concentrator - Switch also Switch - Concentrator)	$\leq$ 1 sec.

T_{SS}

(Switch-to-Switch)	$\leq$ 1 sec.

Thus, the maximum average delay of messages occurs when messages originate at a Service B terminal, are destined for a Service B terminal on a different circuit, and this circuit is connected to a different concentrator at a different switch. This delay is approximately 83 seconds. The average delay of messages originating at new medium speed terminals, destined for similar terminals, located on different circuits, connected to different concentrators, at different switches is approximately 11 seconds. The use of multiplexers instead of concentrators would reduce the delays by about two seconds,

but would have severe impact on cost and processing requirements at the switches.

The NADIN design constraints are structured to ensure reasonable delays for the specified load conditions. Thus, the proper design will vary with the traffic requirements. However, to appraise the basic capacity of the designs produced using the constraints that were developed, the following observations may be made:

- The maximum traffic which can be handled in each direction between two switches is 2.8×10^6 characters per hour or approximately 150% of the 1984 requirement if all messages had to be transferred over a switch-to-switch link. Since a significant portion of the traffic is not expected to require such transfer, there is more than adequate potential capacity in this level of the network.

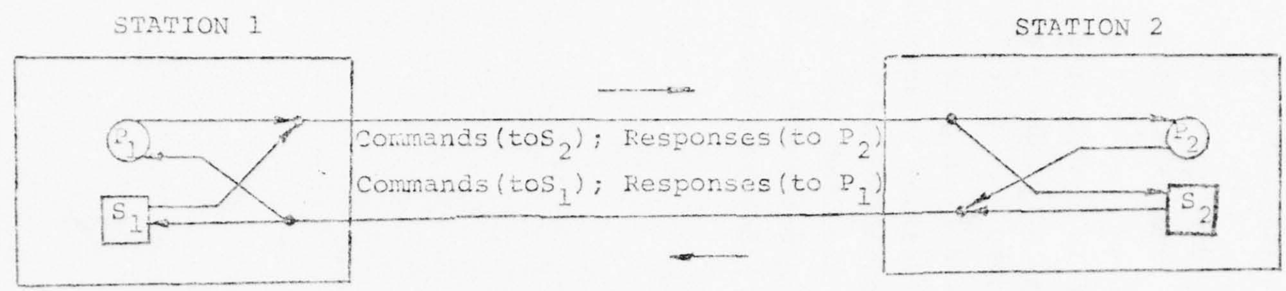
- The maximum traffic which can be handled in each direction between a switch and concentrator is 2.8×10^6 characters per hour. This is almost an order of magnitude more than that expected for even the busiest concentrator.

- The maximum traffic capacity of terminal circuits is 2.2×10^5 characters per hour (with modern terminals on voice grade circuits). This is approximately 30 messages per minute which is considerably more than operator capability, thus assuring reasonable capacity for multidropping in even the busiest cases.

On the basis of these observations, it can easily be concluded that the communication options being considered for the NADIN design are more than adequate for the range of requirements

expected. Design consistent with the constraints developed in this appendix will have reasonable delay performance, be relatively insensitive to errors in traffic projections, and yet be cost-effective in equipment utilization.

The maximum throughput values given above are those that can be achieved with the basic NADIN architecture of concentrators and synchronous high-speed lines interconnecting concentrators and switches. Specific designs in accordance with this architecture use equipment capacity and line speeds appropriate for the actual throughput required, with corresponding costs. The maximum values represent the fundamental capacity of the architecture, and not a design requirement.



POINT-TO-POINT,FULL DUPLEX, SWITCHED OR NON-SWITCHED LINK

FIGURE D-20: PRIMARY/PRIMARY LINK

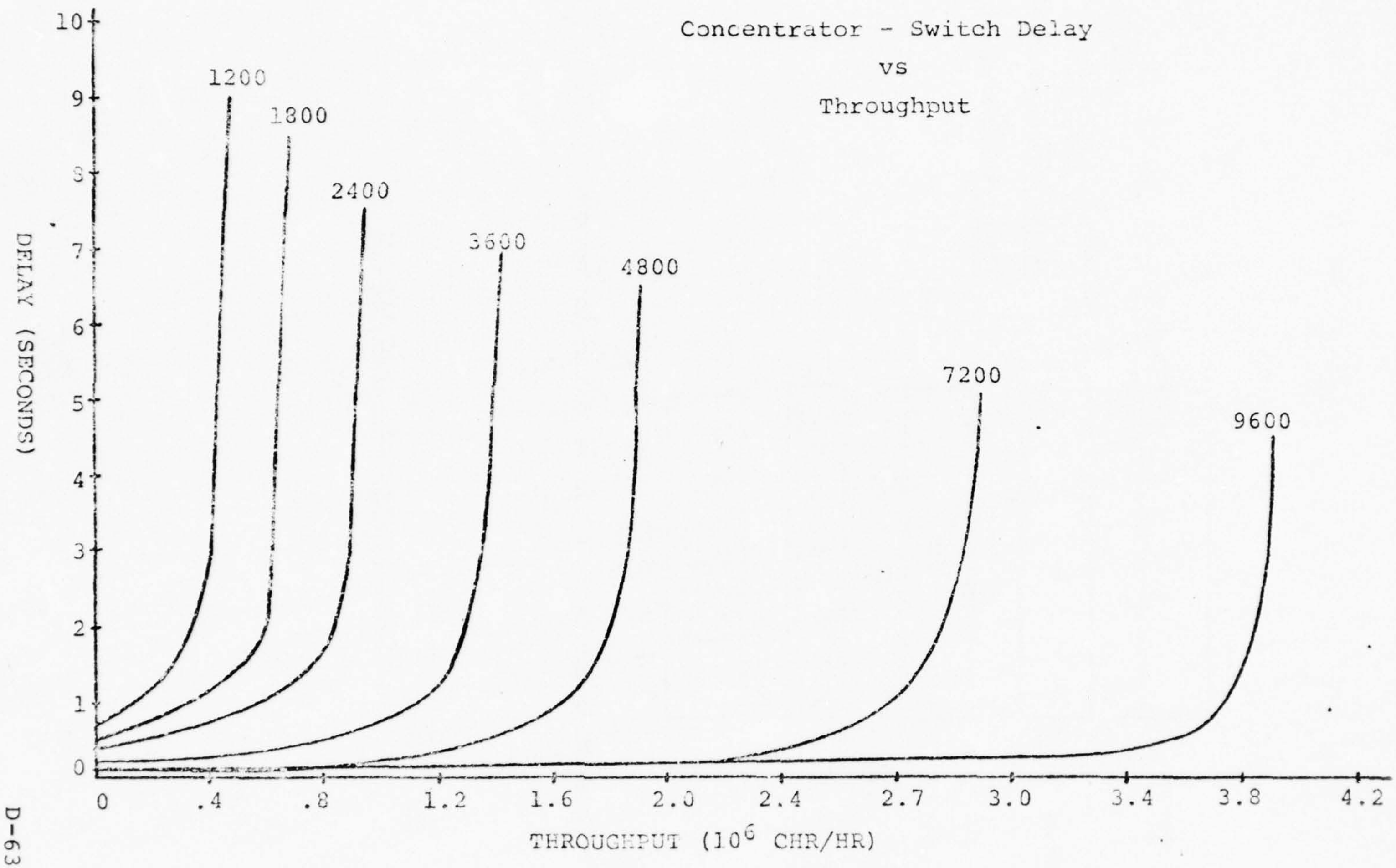
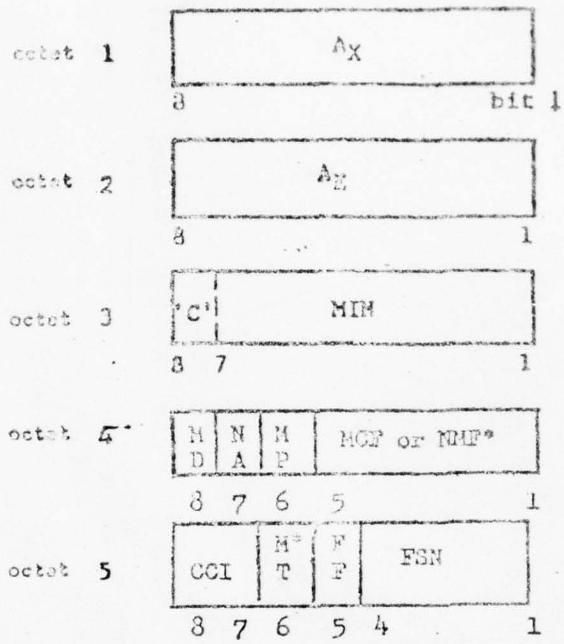


FIGURE D-21: CONCENTRATOR - SWITCH PERFORMANCE



where:

octet 1 is low order octet

bit 1 is low order bit

* When MT is set to 1, MCF in octet 4 is interpreted as NMF.

FIGURE D-22: CCF BASIC FORMAT

Throughput 10^6 CHR/HR	Line Speed bits/SEC	Maximum Delay (T_{CS} and T_{SC}) Seconds
0 - .1	1200	.96
.1 - .3	1800	.82
.3 - .5	2400	.72
.5 - .8	3600	.51
.8 - 1.2	4800	.44
1.2 - 1.9	7200	.32
1.9 - 2.8	9600	.29

TABLE D-6: CONCENTRATOR - SWITCH LINE SPEED SELECTIONS

	CCF INDICATOR	VALUE/RANGE	FUNCTION
A_E	Entry SC address	0-255	entry SC network address.
A_X	Exit SC address	0-255	exit SC network address.
CCI	Communication control indicator	Ø 1-3	Basic CCF format. extended CCF format.
FF	Final frame	Ø 1	not final frame. final frame.
FSN	Frame sequence number	0-15	frame sequence number.
MCF	Message code/format	0-31	one of 32 code/format types.
MD	Multiple dissemination indicator	Ø 1	no re-entry to the CIDIN. message can be re-entered into the CIDIN.
MIN	Message identification number	0-127 'C' = Ø or 1 0-255	message number } NA = 1 alternating count } NA = 1 message number NA = Ø
MP	Message priority	Ø 1	low priority. high priority.
MT	Message type	Ø 1	information message. network management message.
NA	Network acknowledge	Ø 1	acknowledgement not required. acknowledgement required.
NMF	Network management function	0-31	one of 32 network management messages. (see 6.7.3)

TABLE D-7: BASIC CCF INDICATORS

ATTACHMENT 1
7-Unit Coded Character Set
Message Format
AFTN Equivalent

...ge Part			Component of the Message Part	Elements of the Component	Teletypewriter Signal
...ST			Start of Message Signal	One character position 0/1	SOH
			Transmission Identification	a) Transmitting-terminal letter b) Receiving-terminal letter (Example: NRA062) c) Channel-identification letter d) Channel-sequence number (3 digits)	......
			(if necessary) Add'l service indicator	a) One space b) No more than 10 characters	
...DRESS	MESSAGE HEADING	PART OF THE MESSAGE	Alignment Function	Two carriage return, one line feed	<<≡
			Priority Indicator	No change	
			Address Indicator (s)	No change	
			Alignment Function	One carriage return, one line feed	<≡
			Filing Time	6-digit date-time group specifying when the message was filed for transmission	123456
...GIN			Originator Indicator	a) One space b) 6 or 8-letter group identifying the message originator	ABCDEF
			Priority Alarm (No change)	Five character position 0/7 (BELL)	
			Optional Heading Information	Additional data not to exceed the remainder of the line	
			Alignment Function	One carriage return, one line feed	<≡
			Start of Text	One character position 0/2	STX
		THE PERMANENT	Beginning of the text	No change except end each line with one carriage return and one line feed	
			Message Text	End each line with one carriage return and one line feed	
			Confirmation (if necessary)	a) One carriage return, one line feed b) No change	
			Correction (if necessary)	a) One carriage return, one line feed b) No change	
...G			Page Feed Sequence	Optional use of VT (0/11), line feeds, or FF (0/12)	
			End of Text	One character position 0/3	ETX

4.4.18 MESSAGE FORMAT - ICAO

All messages, other than those:

i) prescribed in 4.4.1.5.2.2, 4.4.11.1.5, or 4.4.2

ii) excepted in 3.3.8.1

iii) which are caused to be incomplete as a result of the action prescribed in 4.4.13.7 or 4.4.15.2.

iv) which do require handling on AFTN circuits for any part of their routing.

shall comprise the components specified in 4.4.18.1 to 4.4.18.2 inclusive.

Note. In the subsequent standards relative to message format the following smybols have been used in making reference to the functions assigned to certain signals in the ICAO 7-unit coded character set. (See Annex 10, Volume I, Part 1, page 71 and 72). In most instances graphical symbols have been assigned to other normally nonprinting characters, which should be standardized to the extent possible in accordance with Table ___ on page ___.

Symbol	Signification
←	CARRIAGE RETURN (Character position 0/13)
≡	LINE FEED (Character position 0/10)
△	SPACE (Character position 2/0)

4.4.18.1 HEADING.

The Heading shall comprise all characters from the Start-of-Heading (SOH) up to and including Start of Text (STX), and will be structured as follows:

4.4.18.1.1 FIRST LINE.

The Start-of-Heading (SOH) consisting of character 0/1.

4.4.18.1.2 The Transmission Indentification comprising:

a) Circuit Identification.

b) Channel - sequence number.

4.4.18.1.2.1 Same as 4.4.2.1.2.1., except selection and assignment is by the circuit control station.

4.4.18.1.2.2 Same as 4.4.2.1.2.2.

4.4.18.1.2.3 The Transmission Identification shall be sent over the circuit in the following sequence:

a) Transmitting-terminal letter

b) Receiving-terminal letter

c) Channel-identification letter

d) Channel-sequence number (3 digits)

4.4.18.1.2.4 Additional material may be inserted following the Transmission Identifier when agreed on between the authorities responsible for the operation of the circuit. Such additional material will be preceded by a SPACE (△) and ended by an End-of-Line, consisting of CARRIAGE RETURN (<), LINE FEED (≡). When so such additional material is added the information in 4.4.18.1.2.3 shall be following immediately by CARRIAGE RETURN (<), LINE FEED (≡).

4.4.18.1.3 ADDRESS.

The address shall comprise

a) Priority Indicator

b) Addressee Indicator(s).

Alignment Function (<<≡)

4.4.18.1.3.1 The Priority Indicator shall consist of the appropriate 2-letter group assigned by the originator in accordance with the following:

Priority Indicator	Message Category
SS	Distress messages, distress traffic and urgency messages (see 4.4.1.1.1, 4.4.1.1.2)
DD	Messages justifying the requirement for special priority handling (see 4.4.1.2.3, 4.4.1.2.3.1)
FF(or GG)	Flight safety messages (see 4.4.1.1.3)
GG(or JJ)	Meteorological messages (see 4.4.1.1.4)
GG(or JJ)	Flight regularity messages (see 4.4.1.1.5)
JJ	Aeronautical administrative messages (see 4.4.1.1.6)
KK	Reservation messages (see 4.4.1.1.8)
(as appropriate)	Service messages
LL	General aircraft operating agency messages (see 4.4.1.1.9

4.4.18.1.3.2 Same as 4.4.1.2

4.4.18.1.3.3 Same as 4.4.4.1.2.4.1

4.4.18.1.3.4 The completion of the Addressee Indicator group(s) in the address of a message shall be immediately followed by an Alignment Function.

4.4.18.1.4 ORIGIN

The origin shall comprise:

a) Filing Time

b) Originator

c) Priority Alarm (when necessary)

d) Network Acknowledgement (when necessary)

e) New line (<≡)

4.4.18.1.4.1 The filing time shall comprise the 6-digit date-time group indicating the date and time of filing the message for transmission (see 3.4.2).

4.4.18.1.4.2 Same as 4.4.5.2 (change SPACE symbol to (△)).

4.4.18.1.4.3 The priority alarm shall be used only for distress messages, distress traffic and urgency messages. When used it shall consist of five successive BEL (0/7) characters. (Add Note 2 as Note 1)

4.4.18.1.4.4 The Network Acknowledgement shall be used to indicate when positive accounting of the complete message is required between:

a) Originator and Addressee(s).

b) CIDIN Entry and Exit Centers.

c) Network Interface.

4.4.18.1.4.4.1 When positive acknowledgement is required between the Originator and the Addressee(s) the characters SPACE (△) Escape (1/11) and A (4/1) shall be used.

4.4.18.1.4.4.2 When positive acknowledgement is required between CIDIN centers, the characters SPACE (△) ESCAPE (1/11) and C (4/3) shall be used.

4.4.18.1.4.4.3 When positive acknowledgement is required for the complete message between interfacing networks, over and above link control, the characters SPACE (△), ESCAPE (1/11), and I (4/9) shall be used.

4.4.18.1.4.4.4 Additional characters may be inserted following the Origin line to convey information between the sending and receiving terminal or switching center. This information shall be preceded by SPACE (△) and SOLIDUS) (stroke) (3/10).

4.4.18.1.4.5 The Origin line shall be followed by End-of-Line (<≡) and the Start-of-Text (STX)(0/2) character.

Note 1. In paragraphs 4.4.18.1.4.4.1, 4.4.18.1.4.4.2 and 4.4.18.1.4.43 the code conversion characteristics of the interface between 5 unit and 7 unit coded character sets (applications software) will be required to make the necessary group-of-characters for group-of-characters conversion to insure compatibility between the two procedures.

4.4.18.2 TEXT

The Text of messages shall be drafted in accordance with 4.1.2 when messages will transit part of the AFTN over 5-unit (Baudot Code) circuits. When message texts will be transmitted solely over ICAO-7 circuits and do not conflict with ICAO message types or formats in Doc 4444, administrations may make full use of the characters available in the ICAO-7 code set. Such use is envised for the exchange of file and/or table information or similar data. (See Volume I, pages 71-74).

4.4.18.2.1 Message texts shall conform to the provisions of 4.4.6.2.

4.4.18.2.1 In teletypewriter operation, an End-of-Line Function shall be transmitted at the end of each printed line of the text. When it is desirable to confirm a portion of the Text of a message in teletypewriter operation, such confirmation shall be separated from the last Text group by an additional End-of-Line Function (≤ ≡), and shall be indicated by the abbreviation CFM followed by the portion being confirmed.

4.4.18.2.2 Correction to textual errors shall be made prior to transmission through use of Backspace (0/8) or Backspace (0/8) and Delete (7/15), when the message is prepared off-line, except when the provisions of 4.4.16.1.1b)apply.

4.4.18.2.3 Corrections to textual errors made in on-line operations shall be corrected by inserting SPACE E SPACE E SPACE E SPACE following the error, then retyping the last correct word (or group)

4.4.18.2.4 Except as provided in 4.4.16.1.1b) when it is discovered that an error has been made in the text, the correction shall be separated from the last Text group, or confirmation, if any, by an End of Line Function (≤ ≡) in the case of teletypewriter circuits.

4.4.18.2.5 Stations shall make all indicated corrections on the page copy prior to local delivery or a transfer to a manually operated circuit (Morse or Teletypewriter).

6.4.18.2.6 The tect of AFTN messages shall not exceed 200 groups in length. AFTN messages exceeding 200 groups must be filed in the form of separate messages. Messages, or data, to be exchanged between administrations, switching centers, or similar activities, on medium or high speed circuits may exceed 200 groups as long as the performance characteristics of that network is not diminished.

6.4.18.3 Ending. On teletypewriter circuits the ending of a message shall comprise the following in the order stated:

a) For AFTN messages and messages formatted in accordance with Document 4444 and End of Line Function following the last line of Text shall be followed by Vertical Tab (9/11).

Note: The sequence CARRIAGE RETURN, LINE FEED, VERTICAL TAB shall be recognized by the code conversion function in applications software and converted to letters, carriage return, and seven line feeds upon forwarding to AFTN 5-unit code circuits.

b) For messages not transiting the AFTN network other characters, such as Form Feed (0/12) may be used, providing there is agreement between authorities.

c) End of Text (0/3)

APPENDIX E

RELIABILITY ANALYSIS

E.1 INTRODUCTION

The purpose of this appendix is to consider reliability aspects of the network architectures for NADIN. In particular, it is shown that concentrators (or multiplexers) generally improve the reliability of a large network such as NADIN and that network designs incorporating concentrators can be constrained to ensure reliability without significant cost increase. Such constraints are developed for use in the NADIN design. Some of the results presented here have been taken from the Telcom report (DOT/FAWA2707), dealing with the modernization of Service B, while other results are new.

E.2 RELIABILITY MEASURES

Three measures of reliability are considered:

FNP - The fraction of node pairs which may communicate,

FNC - The fraction of nodes which may communicate with a central switch, and

WTD - The worst case probability that a terminal will be disconnected from a switch.

The FNP measures the general reliability of the network, whereas the WTD measures the worst case reliability that may result from the design. The FNC measures the reliability in terms of the users at least being able to communicate with an intelligent center to which

network status messages and other general administrative messages are generated and received. These three measures were chosen over other reliability measures as these are most indicative of the disruption of service brought about by random failures of components within the system.

E.3 BASIC ASSUMPTIONS

The basic assumption used in the reliability analysis is that all lines connecting two points fail with the same rate. There are several justifications for this assumption. First, empirical data for other systems indicates that this is a reasonable assumption. Second, the exact routing the telephone company will use in constructing the system is not known. The assumption of uniformity of link failure rate makes the analysis invariant under routing. Furthermore, by assuming sequential connection of nodes in the same geographic location, the analysis provides a worst-case bound on performance. Finally, the assumption of non-uniform link failure rates would obscure several significant results which are clear under this assumption.

The network connecting switching centers to one another can be made as reliable as is necessary without affecting the regional nets. The switches, being the most crucial components in the system, are considered independently. Also, the trunk network is 2-connected and thus, the failure of 2 non-adjacent components is required for it to become disconnected. Analytically, the expected fraction of node pairs not communicating in a minimally 2-connected network with N nodes and N links and with probability of operation q_n and q_ℓ, respectively is:

$$P = 1 - \left(N \sum_{i=1}^{N-1} q_\ell^i \, q_n^{i+1} - \binom{N}{2} \; q_\ell^N \, q_n^N\right) / \binom{N}{2}$$

which is negligible in comparison with q_n and q_ℓ in the area of interest.

The use of a dial-up line at each concentrator, which can be used as an alternate path for communication with switches can make the links between concentrators and switching centers perfectly reliable, as the failure of two components (which in the area of interest is negligible in comparison to the failure of one), is now required to disconnect a concentrator from its switching center. Similarly, the presence of a multiplexer at each concentrator and demultiplexer at one concentrator with a sufficient number of spare parts can be used to make all concentrators perfectly reliable. This can be done as long as at least one point possesses sufficient capacity to handle the load of one concentrator. For backup, it might be desirable to provide the additional capacity of another concentrator elsewhere in the network. In addition, since each concentrator possesses dial-up capabilities, protection against switch failures is provided so long as at least one switch has the capacity to handle the load of any other switch. In this case it would be desirable to back up this switch by another similar one at another location. An alternative means of insuring switch reliability is to install highly redundant switches.

E.4 ANALYSIS PROCEDURE

In this section, the analysis procedure for evaluating the FNP and FNC measures are discussed. In the next section, several results of applying this procedure are presented and discussed. The discussion of the WTD measure follows.

E.4.1 General Procedure

Many evaluations performed on graphs which are trees can often be efficiently carried out by recursion. Given subtrees which have been evaluated, a larger subtree con sisting of the union of these subtrees can be easily evaluated. One can thus build larger and larger subtrees until the entire tree is evaluated. Since the networks being considered can be thought of as trees, with the switching center subnet as its root, the above strategy can be used to carry out evaluations on these networks. Several reliability measures for randomly failing networks can be calculated in this manner, including the FNP and FNC measures described above. It is this strategy which is used in the algorithm described below. The network is assumed to be of tree topology, where if more than two centers are present, they are connected in a star centered on node 1. If the subnetwork connecting the centers is designed for very high reliability compared to the other components of the network, the subnetwork may be replaced in the analysis by a single center, and the one center version of the algorithm may be used.

E.4.2 Analysis Algorithm

For storage purposes in computer methods of solution, it is necessary to impose a linear ordering on the nodes of the tree. This is done by defining a father function, NF, on the nodes of the tree. Suppose we have a tree of NN nodes {1, 2, ..., NN} where the nodes have been labeled in natural order. For each node i, except node 1, which is the root of the tree, we define NF (i) = j if $j < i$ and (i, NF(i)) is a link in the network. NF(1) is arbitrarily set to be -1. Thus, associated with each node i is a rooted subtree consisting of nodes with greater numbers which are connected to i by a path passing through nodes with levels $\geq$ i.

Now, let us consider how to calculate the reliability measures of a tree network assuming the reliability of its elements, nodes and links, is known.

We associate with each node i, a state vector, which contains information relevant to the reliability criteria we wish to calculate. Let

> R(i) = Expected number of node pairs communicating in the subtree rooted at node i,
>
> S(i) = Expected number of nodes in the subtree rooted at i which can communicate with i.

Initially, the state vectors represent a disconnected set of nodes. We then define a set of recursion relations which yield the state vector of a rooted tree, given the state of its subtrees. As the algorithm progresses, links (i, NF(i)) are brought into the tree, merging subtrees into larger ones, and the state vector of NF(i) is updated to reflect the presence of each new link considered. When the algorithm terminates, the state vectors represent the state of the entire network and reliability criteria can be otained directly from the state vector of mode 1 without consideration of any other node.

Associated with each node i in the the network, (there are NN nodes) we have

> PN1(i) - Probability of node i operating,
>
> PN2(i) - PN1(i) for nodes which are not terminals; 1 for terminals
>
> PL(i) - Probability of link (i,NF(i)) operating.

Nodes 1, ... , NCEN are switching centers,

NCEN + 1, ... , NCN are concentrators, and

NCN + 1, ... , NN are terminals.

If there is more than one switching center, the father of the tree is arbitrarily selected from among them and set to be node 1. A parameter ISWITCH is used to indicate whether a concentrator can or cannot perform local switching, with ISWITCH = 1 indicating switching.

The algorithm consists of the five steps presented below. A discussion of the algorithm follows its presentation.

STEP 1: (Initialization)

```
Set R(i)  = 0
    S(i)  = PN1(i)
for all nodes i = 1, ... , NN
Set i = NN
```

STEP 2: (Subtree)

```
Set j = NF(i)
R(j) = R(j) + R(i) * PN2(j) * PL(i) * + S(i) * PL(i)
S(j) = S(j) + S(i) * PN1(j) * PL(i)
i = i - 1
If i ≥ NCEN, then go to Step 2.
```

STEP 3: (Switching)

```
If ISWITCH = 0, then go to Step 4.
For i = NN, ... , NCEN + 1, do the following:
     Set j = NF(i)
     R(j) = R(j) + R(i) * (1-PL(i)) + (1-PN1(j)) * R(i)
     * PL(i)
```

STEP 4: (Multiple Centers)

If there is only one center, then go to Step 5.

For $l = 2, \ldots, NCEN$, do the following:

$R(1) = R(1) + R(i) + S(1) * S(i) * PL(i)$

$S(1) = S(1) + S(i)$

STEP 5: (Evaluation of Measures)

$$FNP = \frac{R(1)}{2^{NN}}$$

$$FNC = \frac{S(1)}{NN}$$

In Step 1, the state vector components are initialized, with the number of node pairs communicating being zero (as no links have been considered yet) and the number of nodes communicating with i is simply the probability that i itself is operational.

Step 2 is the basic recursive step of the algorithm. When a new link (i, NF(i)) is considered, the number of node pairs communicating through j = NF(i) is simply the previous number, R(j), plus the number communicating through i times the probability that both node j and link i are operational, plus the product of all those communicating to i times all those communicating to j times the probability of the joining link being operational. Similarly, the number of nodes which can communicate with node j, S(j), is the previous number, plus those which can communicate with i times the probability that j is operational and the probability that the connecting link is operational. The justification for using PN2(i) = 1 for terminals is that the failure of terminal does not affect the ability of other node pairs to communicate, as communication does not take place through the terminal, but the expected

number of nodes that can communicate with node i does depend on the operability of node i.

In Step 3, the impact of concentrators doing local switching is evaluated. When concentrators do local switching, nodes can communicate through them even if either, or both, the trunk line connecting the concentrator to the center fails, or the center itself fails. However, the expected number of nodes that can communicate with a center is not affected by whether concentrators switch or not. Thus, entering Step 3, the state vectors for all centers have been calculated. Then, for each concentrator, the number of node pairs which can communicate in the subtree rooted at its center is not only the basic number, R(j), but this number plus those which communicate through the concentrator if the switch is failed, or if the switch is operational but the link is failed.

Step 4 simply sums the pairs which communicate locally through their switch and those communicating over the link joining the switches. The final evaluation of the measures as functions is conducted in Step 5.

E.5 BASIC RESULTS

The basic results of applying the above algorithm to appraise the reliability impact of using concentrators in a network such as NADIN have been reported in the initial NAC -Telcom study (DOT/FAWA2707). Some of these results are reproduced here for completeness. In addition, new results are presented on the impact of using switching concentrators versus nonswitching concentrators.

E.5.1 Use of Concentrators

In the previous study, designs using concentrators at each ARTCC were contrasted with designs that used only properly constrained voice grade lines and only properly constrained

teletype lines. The reliability characteristics of the designs are portrayed in Figures E-1 and E-2. It is immediately clear when the figures are examined, that the design using concentrators is significantly more reliable than the voice grade designs under consideration, even without the use of any additional equipment to improve its reliability. This result is not surprising in light of the relative design configurations. The design using concentrators is primarily composed of a large number of small trees rooted at the concentrators, while the other designs are primarily composed of much larger trees rooted at the switching centers. The average number of links between a node and its associated relay center is much smaller in the design using concentrators and, therefore, this design is more reliable than the others.

Another advantage of the use of concentrators is that they provide an intermediate step in the chain from node to switching center. Since there is a small number of concentrators relative to the total number of terminals, we can, without appreciably increasing the cost of the system, add additional equipment at each concentrator and considerably increase the system reliability. The results using dial-up lines and multiplexers at the concentrators bear out this conclusion.

We can make an observation about the form of the curves in Figures E-1 and E-2, which yields some insight into the results themselves. The curves are, in fact, nearly straight lines. This in itself is not surprising since, analytically, the reliability criteria are low order polynomials in variables whose values are much smaller than 1 in the area of interest to us. The order of the polynomial is essentially the average number of links in the path from node to relay center in each design. By minimizing this, we maximize reliability.

Thus, the general conclusion is drawn that the concentractors serve to improve the reliability aspects of the network tepology.

Another conclusion drawn in the previous study was that "the network is most reliable with the fewest number of switches." This is based on the observations that the average fraction of terminals communicating with switches, FNC, is independent of the number of switches, but the average fraction of terminal pairs communicating, FNP, varies as a function of the number of switches, as shown in Figure E-3.

E.5.2 Impact of Concentrator Switching

Though not mandatory the concentrator may be designed to perform message switching on a local basis. Several questions need to be resolved to determine whether the local switching function should be specified for the concentrators. Included are the need for journaling capability to be present only at switches, the additional cost of implementing the switching function, the impact of switching local traffic at the concentrators on the processing requirements of the central switches, the benefits to the local users on having local switching capability during switch outages, and the impact of local switching on the global measures of network reliability. It is the last question which is answered here.

The FNP measure of reliability is shown in Figures E-4, E-5, and E-6 for both cases of switching and nonswitching as a function of central switch downtime when concentrator failure is as likely as a basic link failure. As is immediately clear, the switching capability of the concentrators gives an insignificant increase in reliability according to this measure. This is easily understood. When a switch fails, the number of terminal pairs which can communicate through the concentrators is only the sum of the numbers which can communicate through each concentrator, whereas, when the switch is

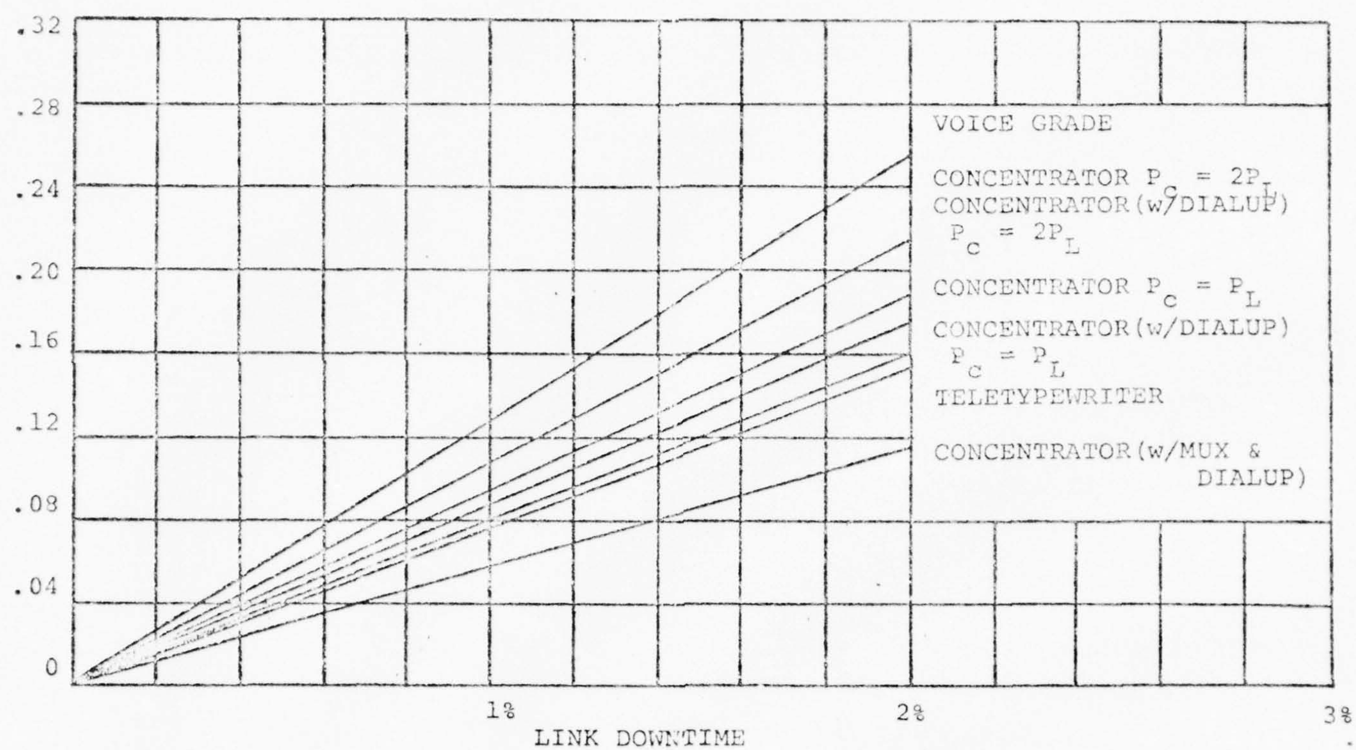


FIGURE E-1: EXPECTED FRACTION OF TERMINAL PAIRS NOT COMMUNICATING WHEN ALL SWITCHES ARE OPERATING

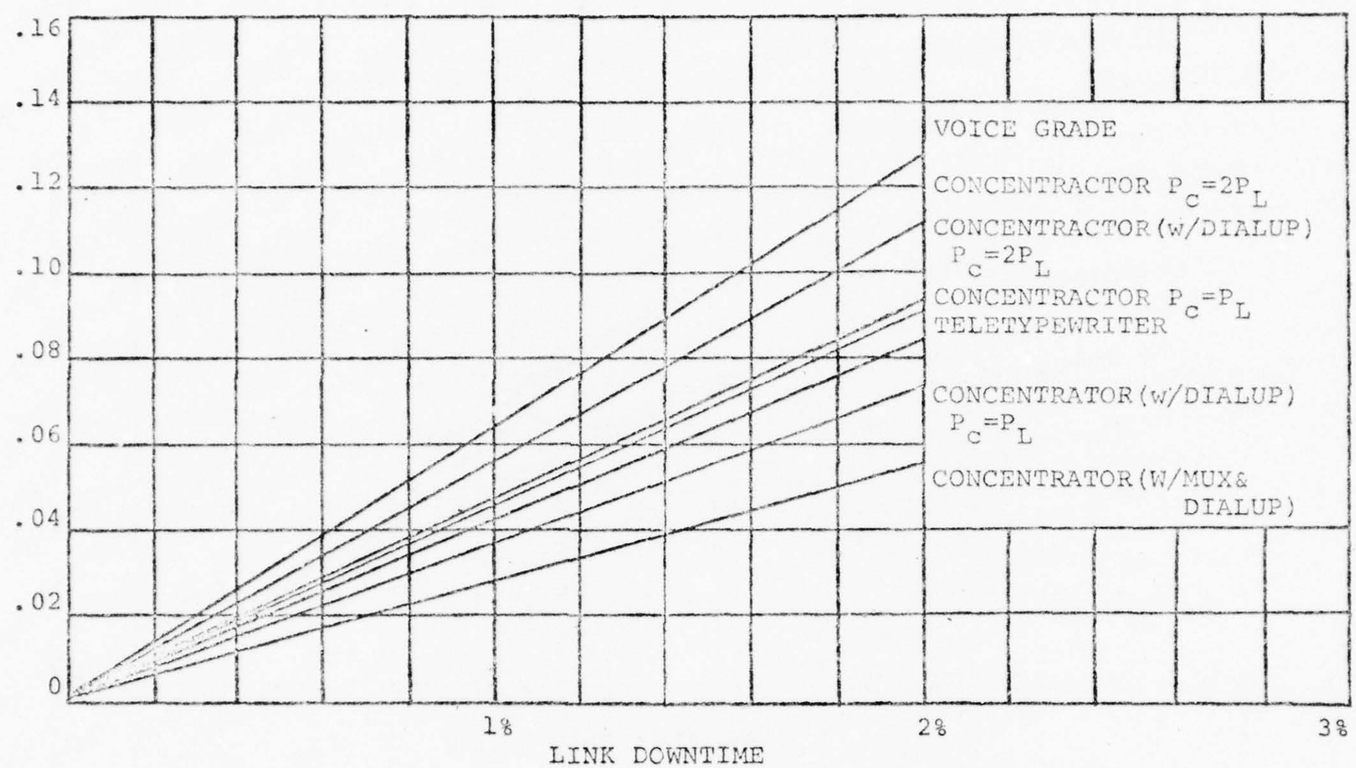


FIGURE E-2: EXPECTED FRACTION OF TERMINALS NOT COMMUNICATING WITH SWITCHES

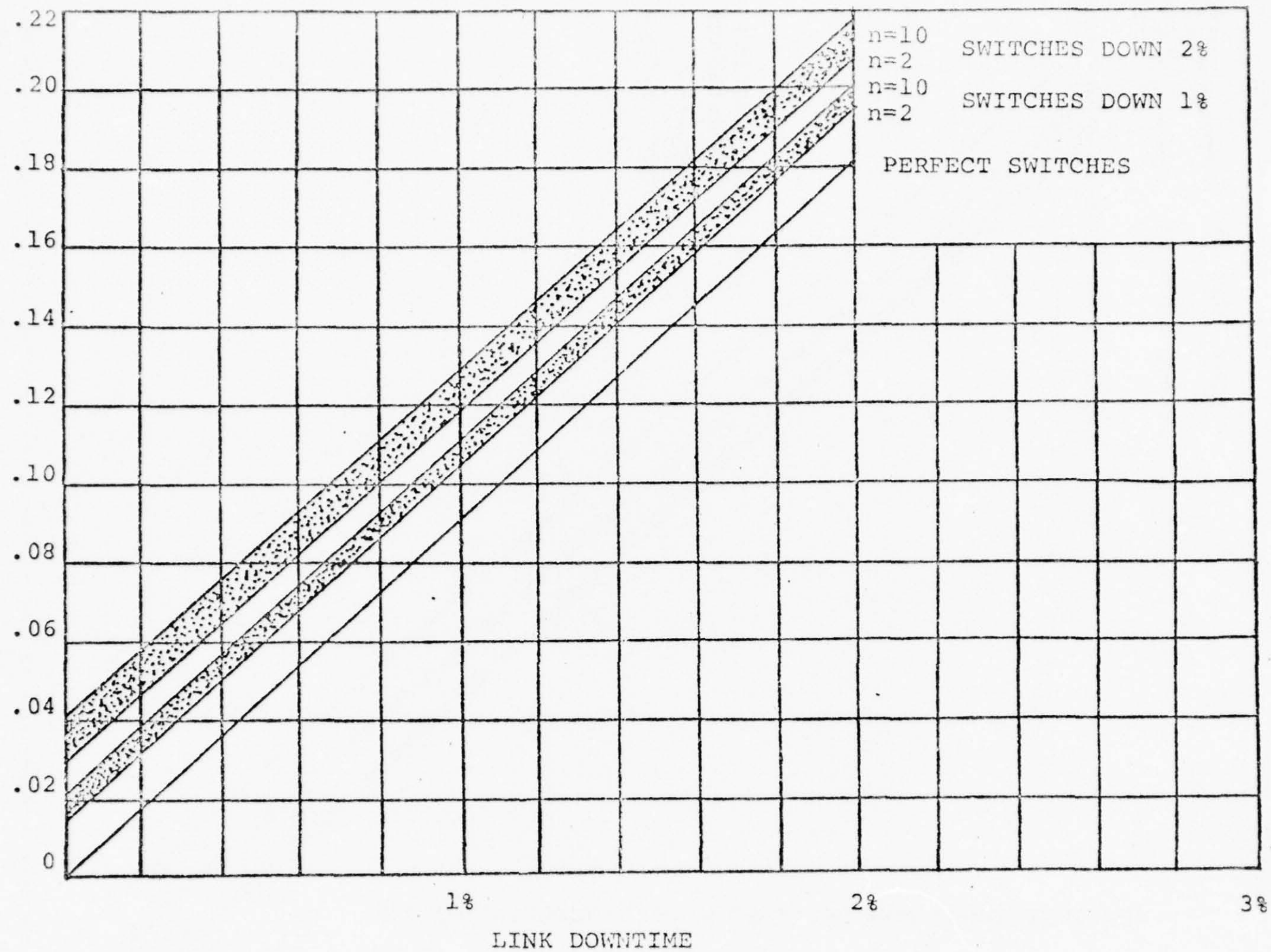


FIGURE E-3: EXPECTED FRACTION OF TERMINAL PAIRS NOT COMMUNICATING IN NON-REDUNDANT CONCENTRATOR DESIGN

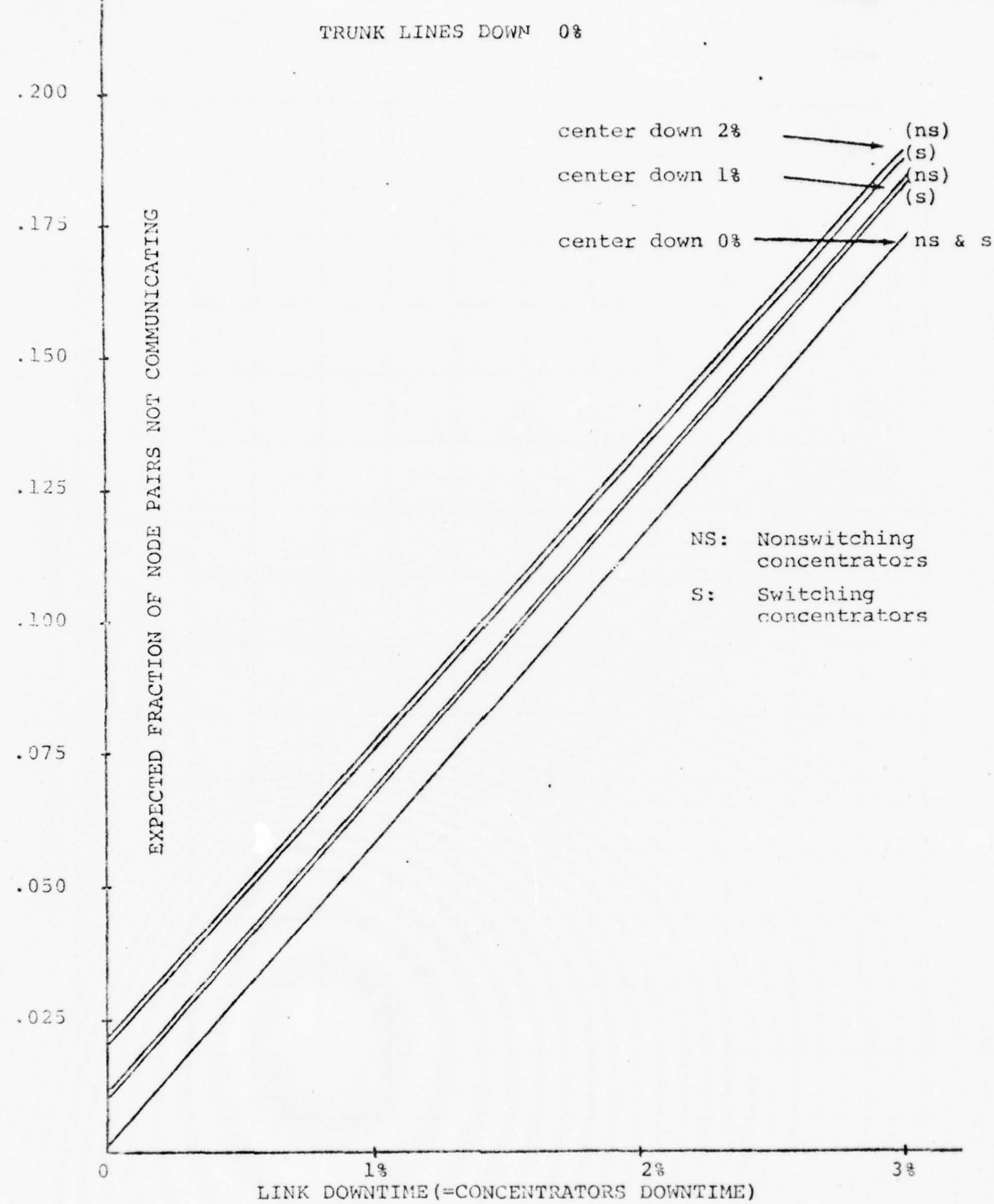

TRUNK LINES DOWN 0%
.200
.175
.150
.125
.100
.075
.050
.025
EXPECTED FRACTION OF NODE PAIRS NOT COMMUNICATING
center down 2%
(ns)
(s)
center down 1%
(ns)
(s)
center down 0%
ns & s
NS: Nonswitching concentrators
S: Switching concentrators
0
1%
2%
3%
LINK DOWNTIME (=CONCENTRATORS DOWNTIME)

FIGURE E-4

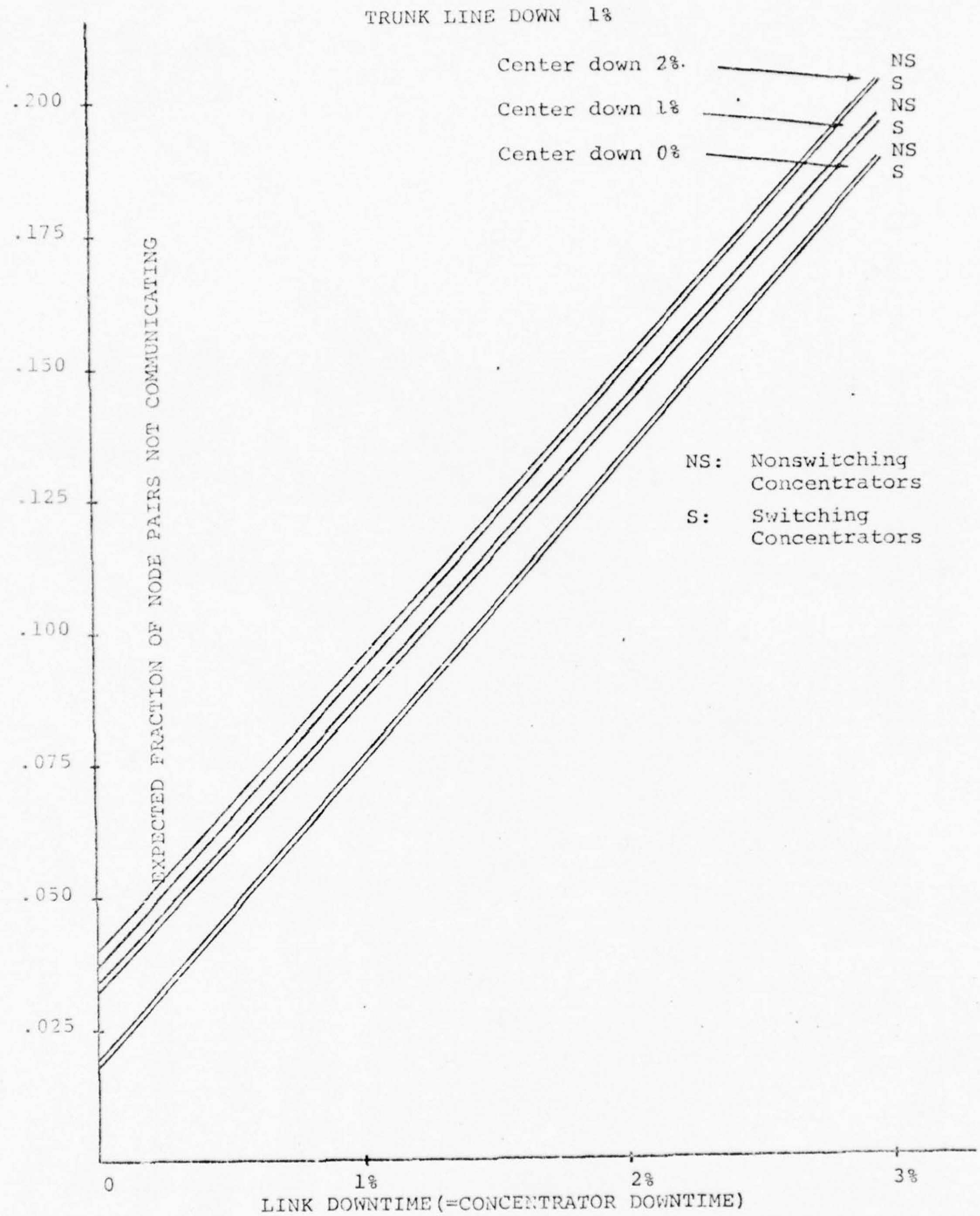
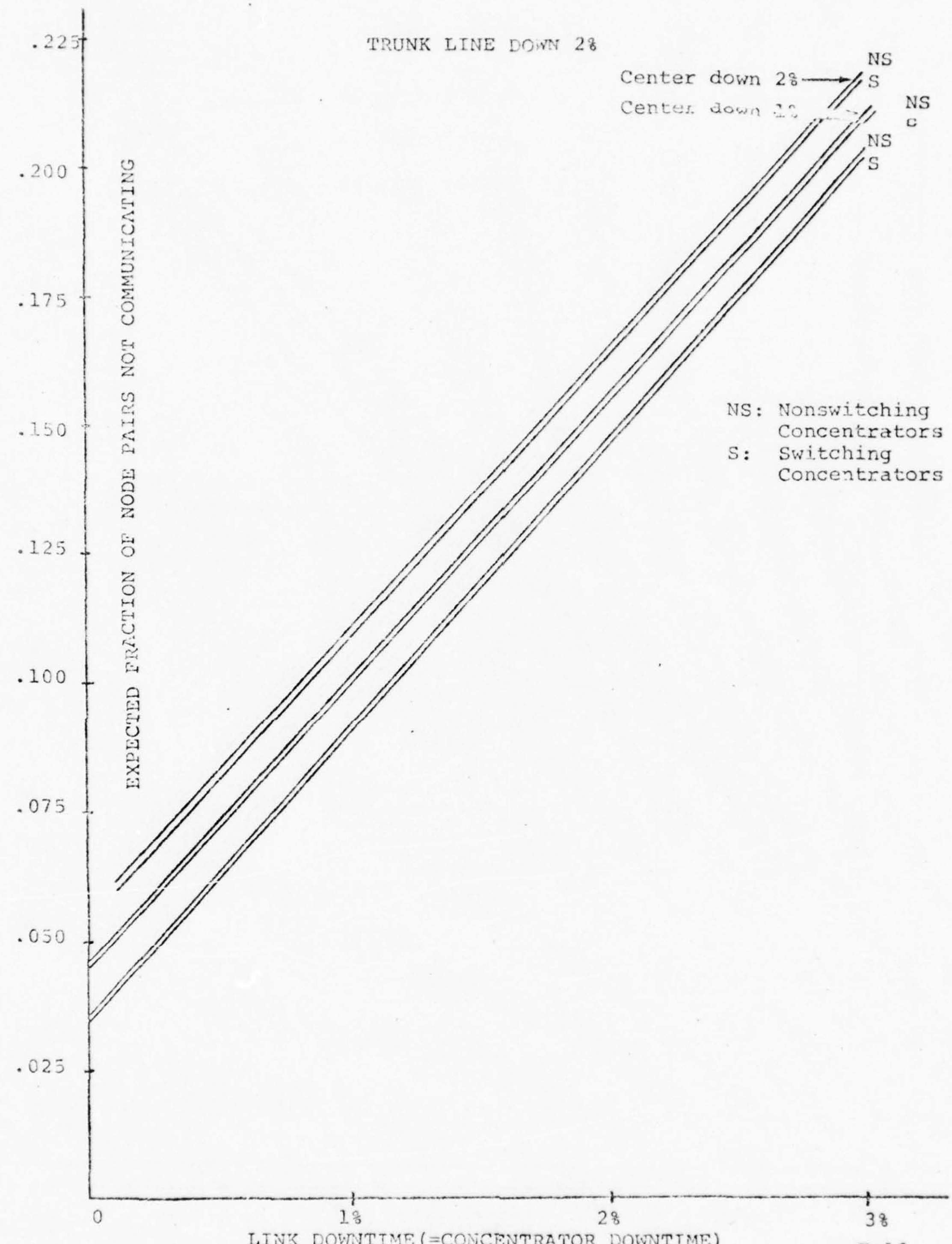

TRUNK LINE DOWN 1%
Center down 2%
Center down 1%
Center down 0%
NS
S
NS
S
NS
S
.200
.175
.150
.125
.100
.075
.050
.025
EXPECTED FRACTION OF NODE PAIRS NOT COMMUNICATING
NS: Nonswitching Concentrators
S: Switching Concentrators
0
1%
2%
3%
LINK DOWNTIME (=CONCENTRATOR DOWNTIME)

FIGURE E-5



TRUNK LINE DOWN 2%
Center down 2%
Center down 1%
NS
S
NS
S
NS
S
NS: Nonswitching Concentrators
S: Switching Concentrators
EXPECTED FRACTION OF NODE PAIRS NOT COMMUNICATING
.225
.200
.175
.150
.125
.100
.075
.050
.025
0
1%
2%
3%
LINK DOWNTIME (=CONCENTRATOR DOWNTIME)

FIGURE E-6

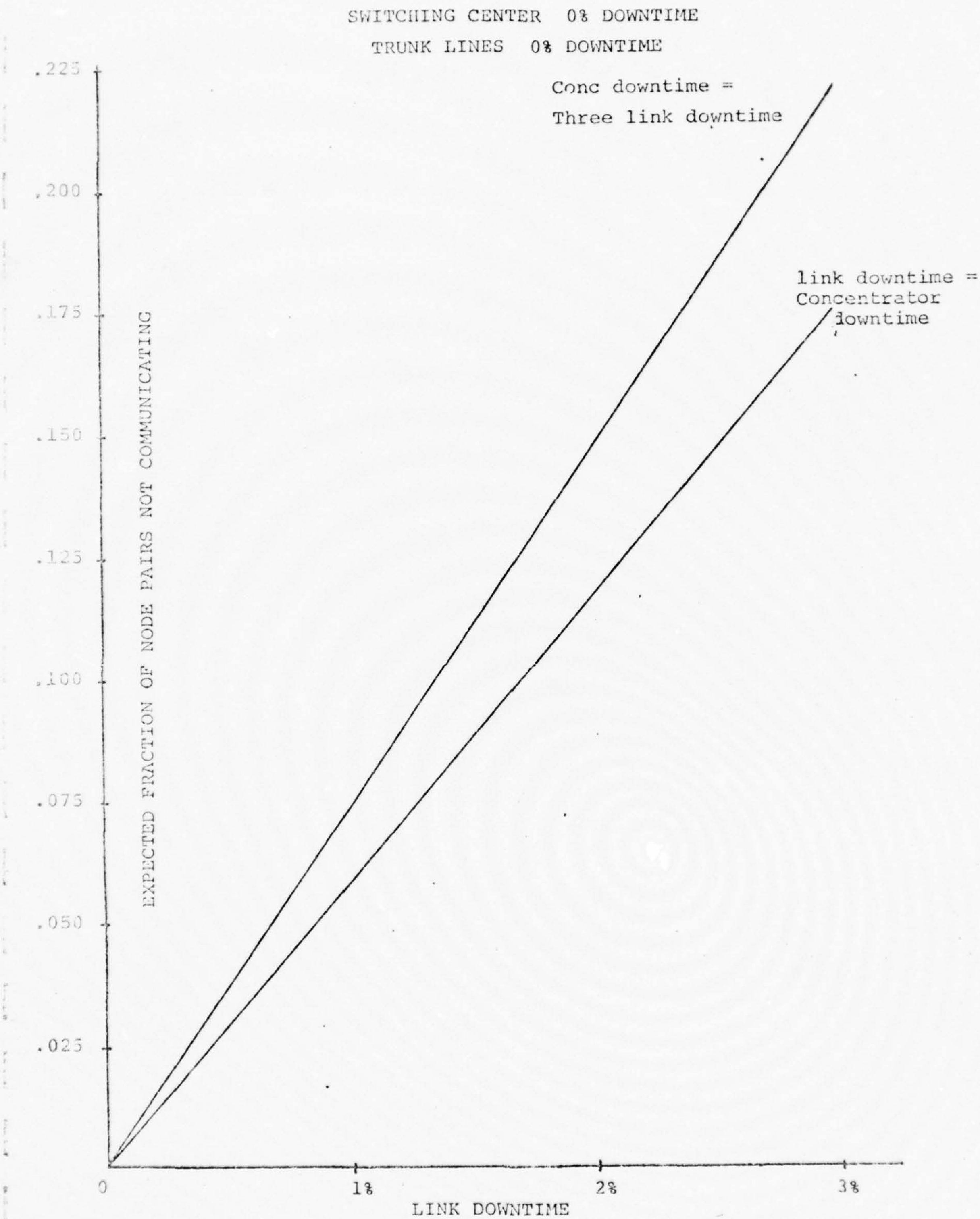

SWITCHING CENTER 0% DOWNTIME
TRUNK LINES 0% DOWNTIME
Conc downtime =
Three link downtime
link downtime =
Concentrator
downtime
.225
.200
.175
.150
.125
.100
.075
.050
.025
0
1%
2%
3%
EXPECTED FRACTION OF NODE PAIRS NOT COMMUNICATING
LINK DOWNTIME

FIGURE E-7

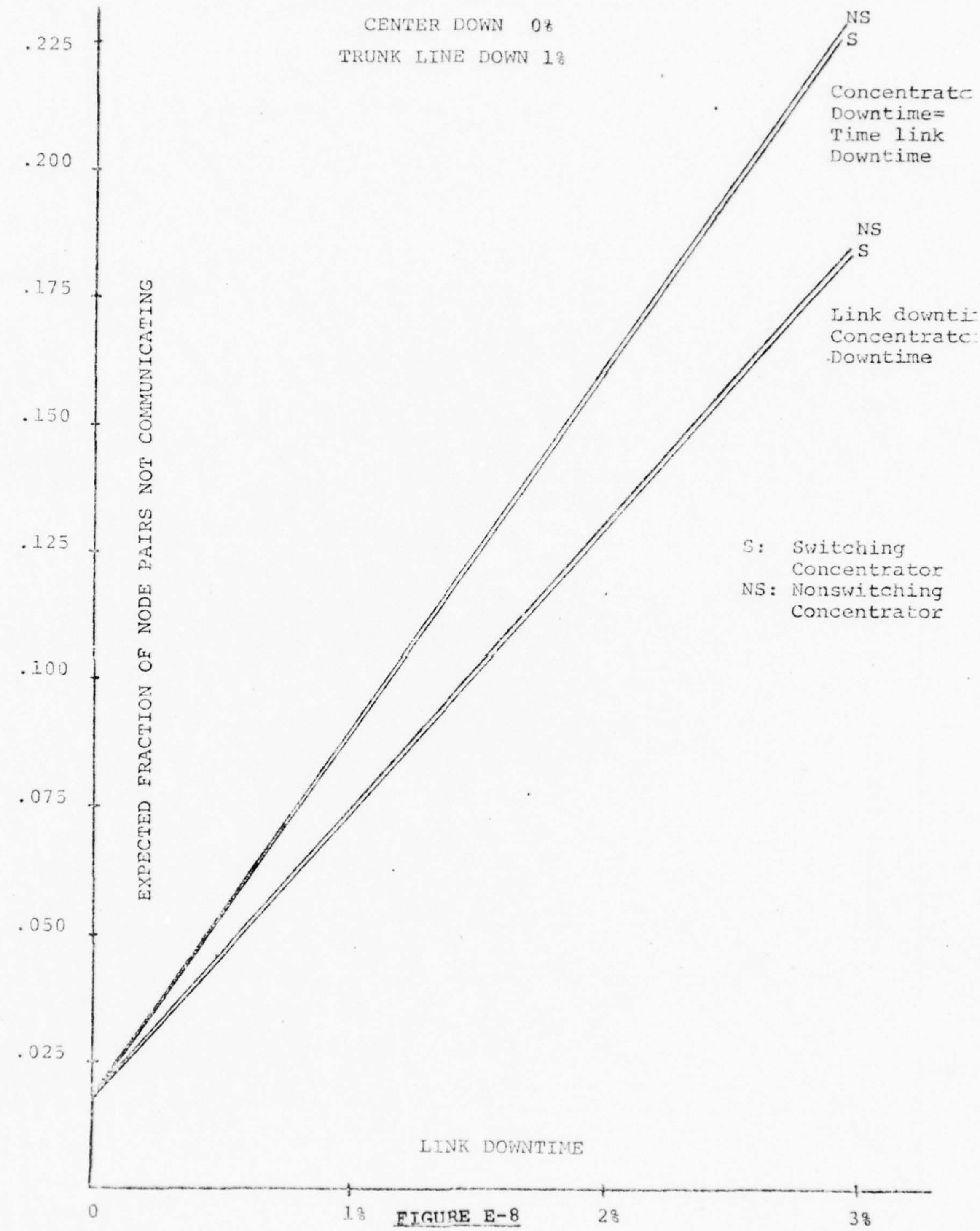

CENTER DOWN 0%
TRUNK LINE DOWN 1%
.225
.200
.175
.150
.125
.100
.075
.050
.025
EXPECTED FRACTION OF NODE PAIRS NOT COMMUNICATING
NS
S
Concentratc
Downtime=
Time link
Downtime
NS
S
Link downti:
Concentratc:
Downtime
S: Switching Concentrator
NS: Nonswitching Concentrator
LINK DOWNTIME
0
1%
2%
3%

FIGURE E-8

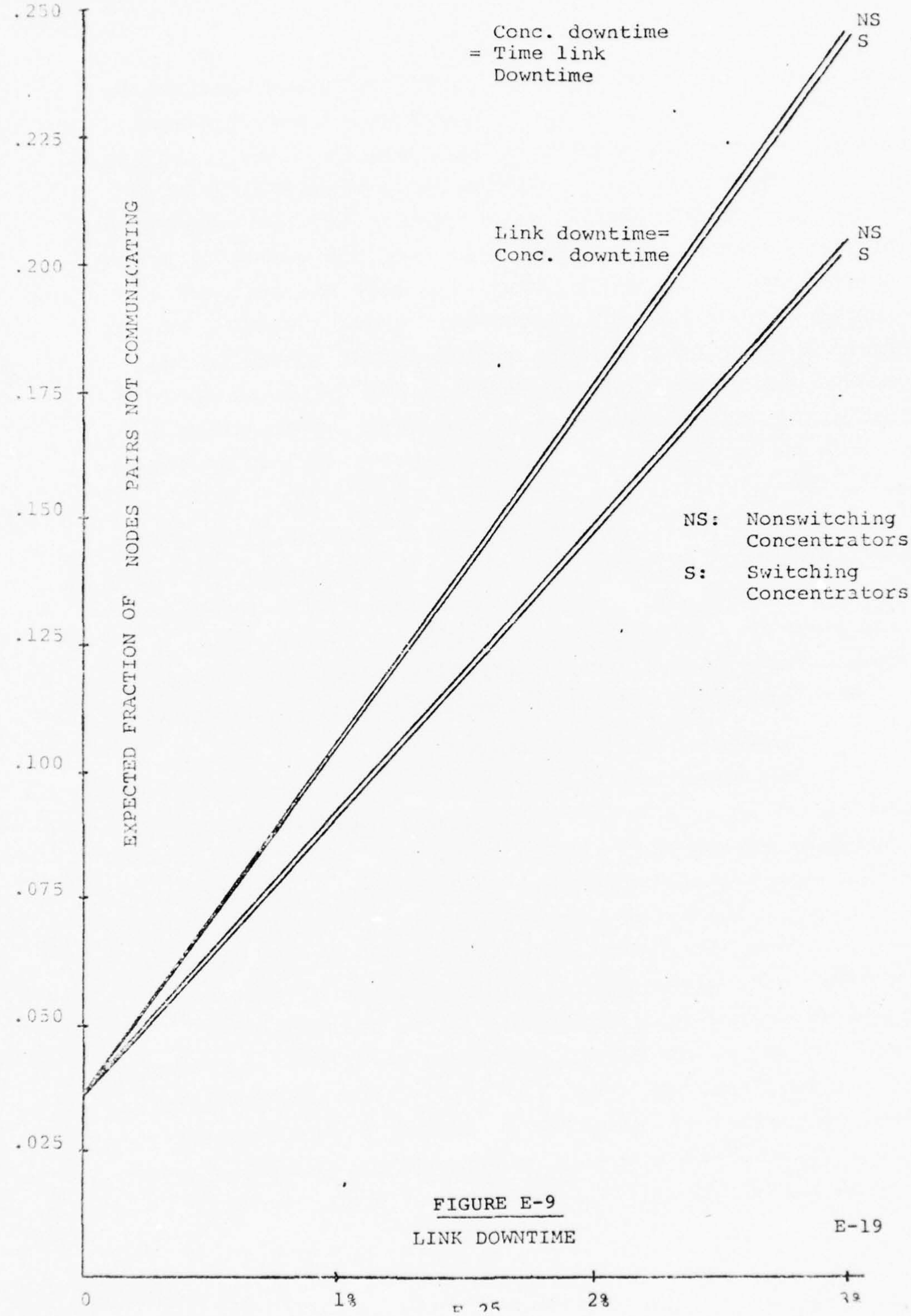


FIGURE E-9

LINK DOWNTIME

operable, the total number is the number of pairs that can be formed from the total number of terminals, a much larger number, that dominates the reliability measure. This observation is reinforced by the results portrayed in Figures E-7, E-8, and E-9, showing the FNP measure as a function of concentrator reliability and trunk line reliability when the switching center is assumed operable. Notice that when both the switching center and trunk lines are assumed operable, (Figure E-7), there is no difference between switching and non-switching concentrators. This is to be expected, as the local-area switching concentrators are only beneficial in providing service when the switching capability of the center is unavailable.

As a final note, it should be recognized that the switching function of concentrators has no impact on the FNC measure of reliability. Thus, on the basis of the above results, it may be concluded that in terms of global measures of network reliability, concentrators which switch have no significant advantage over concentrators which do not switch.

E.6 DESIGNING RELIABLE NETWORKS

The above results indicate the positive impact on reliability of using concentrators in the network design. In this section, we consider another measure of reliability directed at ensuring a level of reliable service to all users. Network designs are often developed on the basis of line constraints intended to ensure a specified level of performance. Such a constraint may result in a large number of terminals being placed on a single multipoint line. The Bell System recommends that no more than 20 stations be placed on a single multipoint facility due to the fact that, "the complexity of networks consisting of more than 20 points is such that the time required to restore service following outages and the increased number of outages as the number of points increases,

cause channel availability to be less than can be tolerated by many data systems." (Tech Ref. PUB 41004 - Data Communications Using Voiceband Private Line Channels, October, 1973). In particular, some rather primitive and conservative statistics gathered by the Bell System indicate an average link availability of approximately .998. With this assumption, design constraints of 20, 10, and 5 stations per line translate into worst case terminal circuit availability (WTD) of .96, .98, and .99 respectively. Thus, a network design constraint of 5 stations per line is used to meet a basic objective of (.99)worst case circuit availability (WTD).

When concentrators are not used, the impact on leased line cost of a 5 terminals per line constraint versus a 20 terminals per line constraint is severe, resulting in approximately a 60% cost increase. However, with concentrators, only about 7% increase is incurred.

E.7 SYNTHESIZING A RELIABLE NETWORK

Since there is a large number of terminals connected to a switch through concentrators, improvements in concentrator reliability and the reliability of concentrator links to the switching centers can significantly increase overall network reliability. Improvements can be made without appreciably increasing the cost of the system because there are few concentrators relative to the total number of terminals. The fraction of terminals not communicating with switches as a function of average switching downtime is shown in Figures E-10 and E-11 for the following three cases.

a. No attempt is made to improve the reliability.

b. Additional equipment is added to assure that there is always a path from any concentrator to an associated switch.

c. In addition to the improvement made in b, additional equipment including multiplexing is used to make the concentrator facility nearly perfectly reliable.

The more useful criterion the expected fraction of terminal pairs that communicated (FNP) as a function of average switch downtime and of the number of switches, for the above three cases, is shown in Figures E-3, E-12, and E-13.

There is no way to make a path from a concentrator to switch completely reliable. However, there are several ways to achieve near perfect reliability (that is, to make the failure rate negligible when compared to the failure rate of other elements). To achieve such reliability for the path between a concentrator and its associated switch, one can either:

a. Have an additional leased line from the concentrator to the switch so that there are two diverse paths between them, or

b. Have dial-up equipment at concentrator and switch sites so that if the regular path is broken, the path between the concentrator and the switch can be reestablished by dialing through the switched network.

The second method is less convenient since human intervention may be necessary, unless auto-dial equipment is used, and there will be momentary delays during the switch-over. However, this method is less expensive. To make the concentrator almost completely reliable, one can either:

a. Place a redundant concentrator at each concentrator site so that if the primary concentrator fails, its load can be assumed by the backup concentrator, or

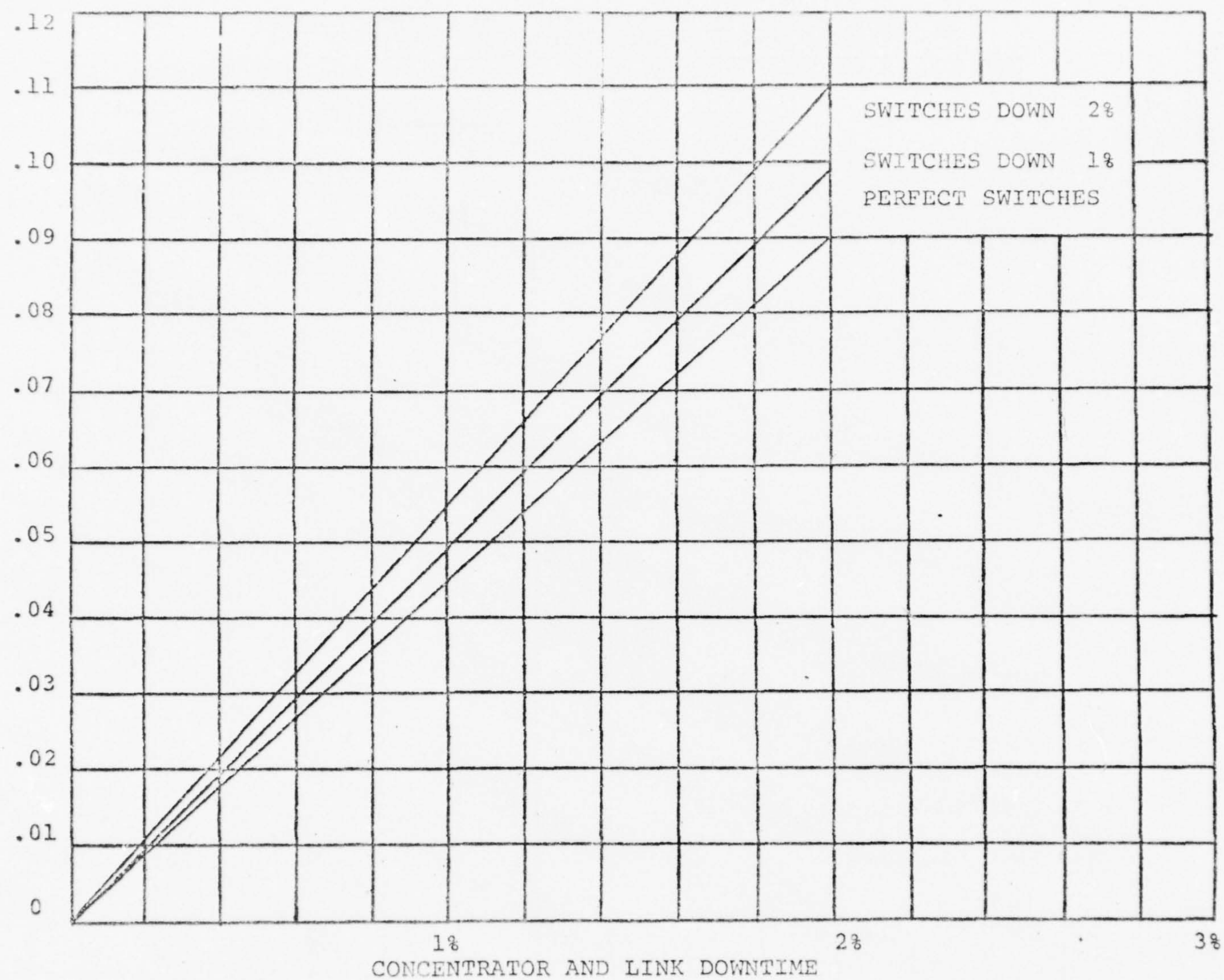


FIGURE E-10: EXPECTED FRACTION OF NODES NOT COMMUNICATING WITH SWITCHES IN NON-REDUNDANT CONCENTRATOR DESIGN

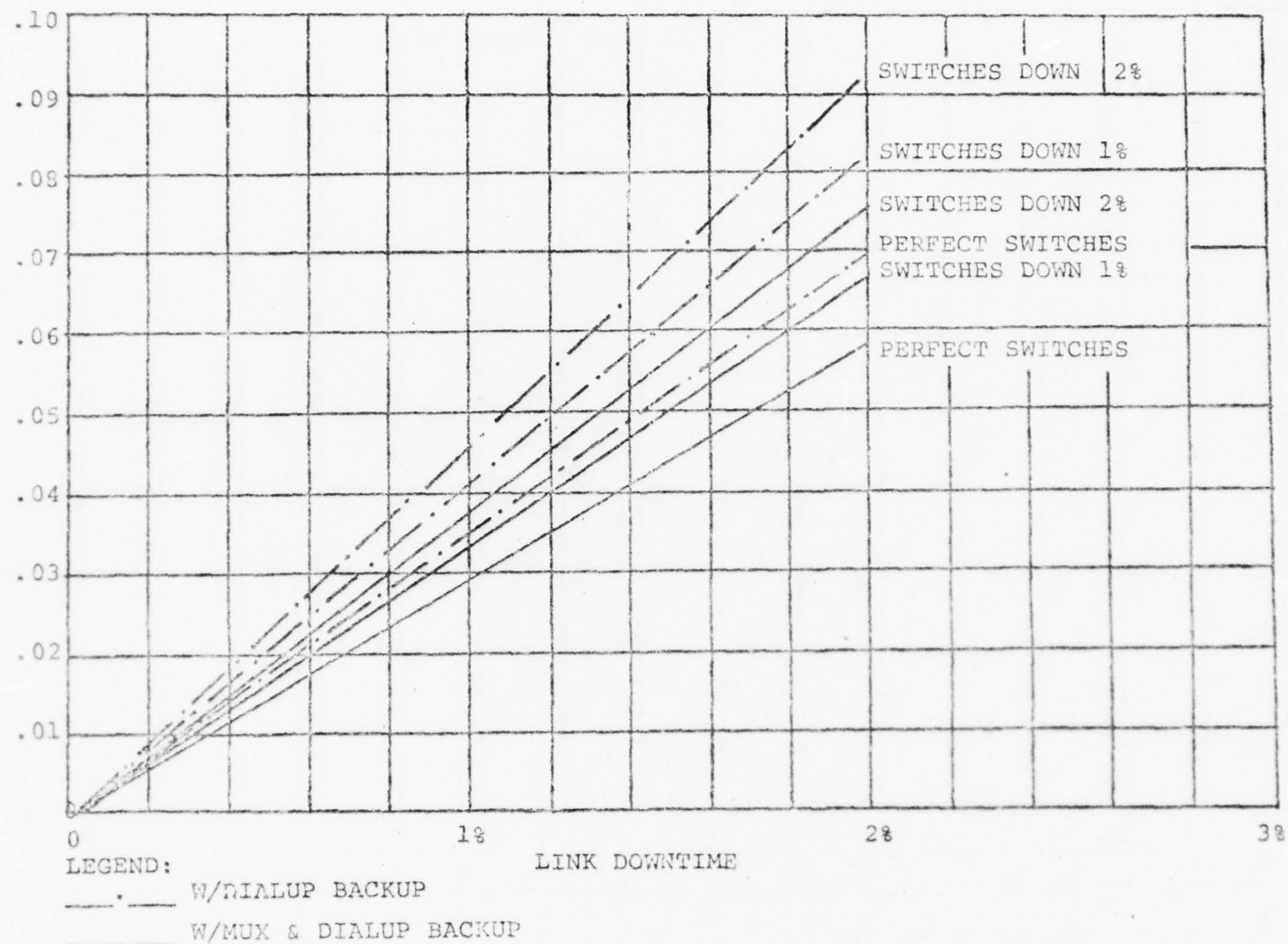


FIGURE E-11 AVERAGE FRACTION OF NODES NOT COMMUNICATING WITH SWITCHES IN CONCENTRATOR DESIGN WITH BACKUP

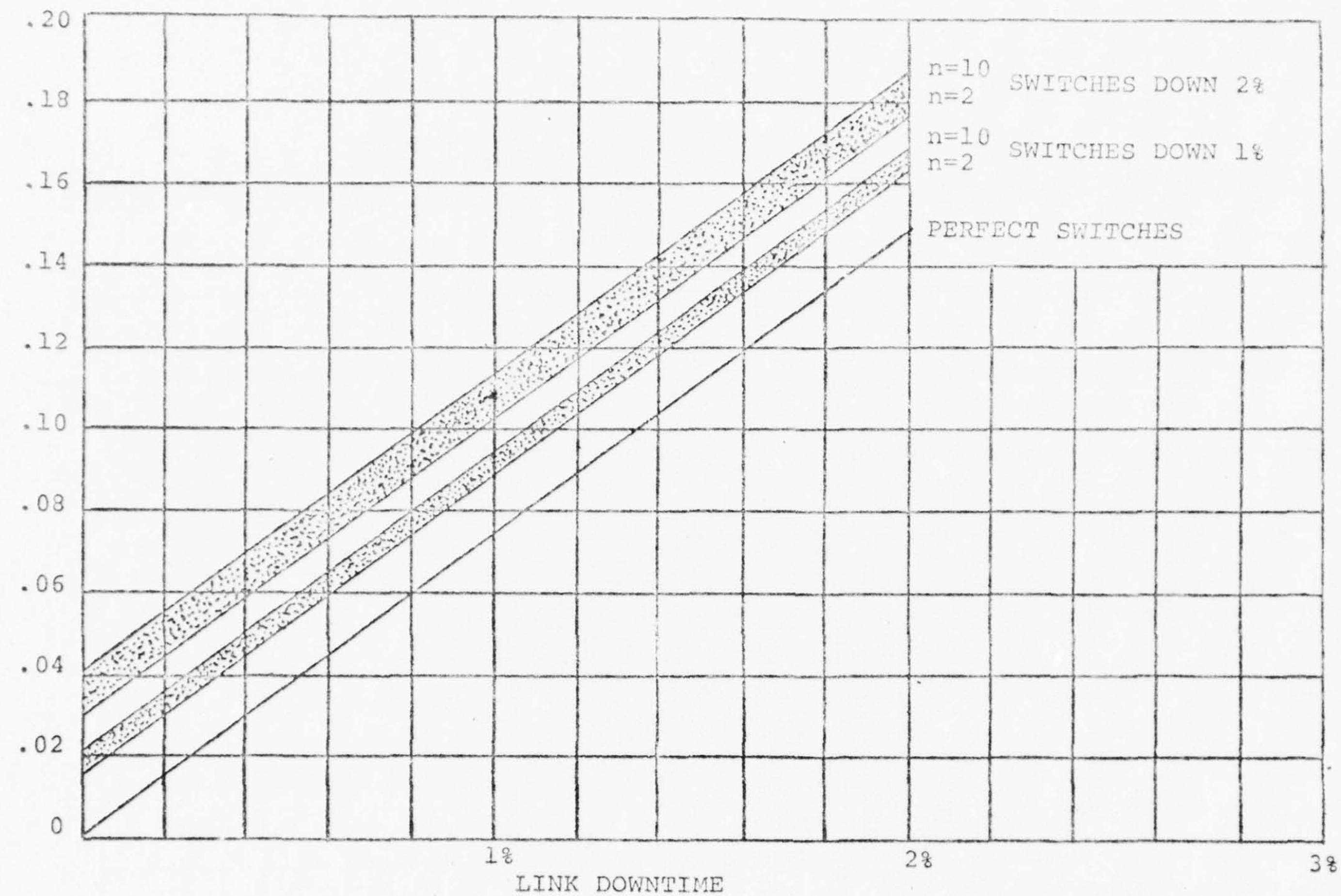


FIGURE E-12 EXPECTED FRACTION OF TERMINAL PAIRS NOT COMMUNICATING IN CONCENTRATOR DESIGN WITH DIALUP BACKUP

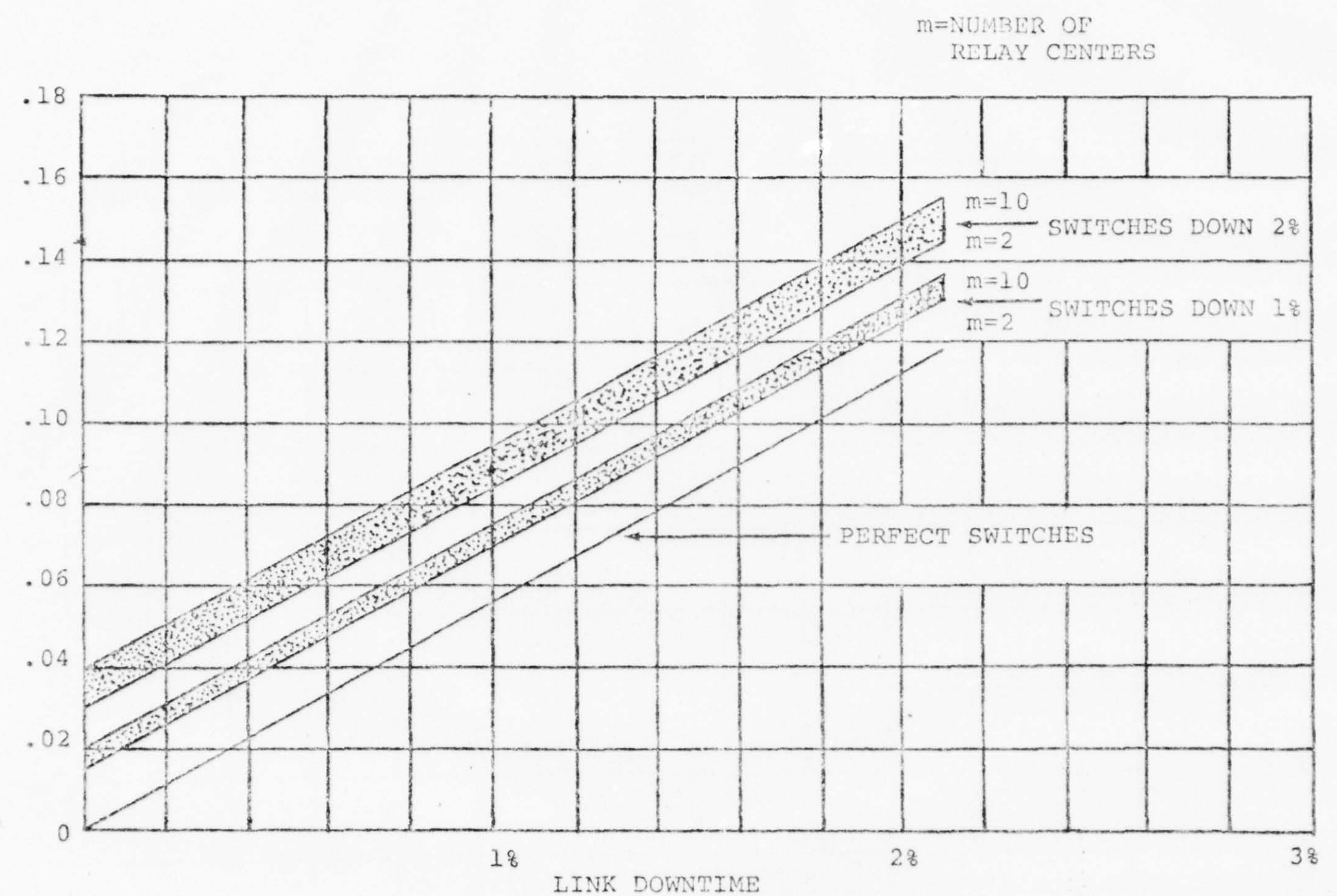


FIGURE E-13 EXPECTED FRACTION OF TERMINAL PAIRS NOT COMMUNICATING IN CONCENTRATOR DESIGN WITH MULTIPLEXOR AND DIAL-UP BACK-UP.

b. Place a multiplexer at each concentrator site and a demultiplexer at any two concentrator (or switch) sites. The two facilities chosen will thus provide routine service to their areas and a back-up service to the other.

If the concentrator fails, all low-speed lines can be multiplexed over the dial-up backup line to one of the two demultiplexers located at the backup facility. Cost comparison for achieving these reliabilities of these backup facilities indicate about a 5% increase in total network cost (excluding switch cost) for the multiplexer and dial-up, and about a 25% increase in cost for a fully redundant design.

As is evident from figures E-12 and E-13, reliability is greatly improved using the appropriate backup equipment. The same improvement in reliability can be obtained by using dial-up vs. leased line backup and by using redundant concentrators vs. multiplexer backup. The extra cost of one method over the other is the price paid for operational ease achieved by using the more expensive method.

E.8 CONCLUSION

The conclusions drawn in this section are summarized below:

The use of concentrators in the network design improves reliability significantly.

Concentrators which perform switching provide only an insignificant increase in reliablity over concentrators which do not perform switching.

The use of concentrators with a line constraint of 5 terminals per line ensures reliable service to all users, with insignificant cost impact.

Reliability can be significantly improved with little increase in cost by using a multiplexing dial-up redundancy scheme.

APPENDIX F

EQUIPMENT CONSIDERATIONS

F.1 INTRODUCTION

The purpose of this appendix is to define functionally the equipment components that may be used in NADIN and to estimate a reasonable cost for these components in the configurations in which they would be used in the NADIN. The cost also includes redundancy for reliability where it is appropriate. The basic monthly cost (10 percent amortization over 10 years) was calculated by doubling the purchase price and dividing by 120, giving a slightly higher result than would use of the annuity formula.

F.2 TERMINALS

Three basic terminal types are considered:

a. Existing Model 28 teletypes,

b. Modification of existing Model 28 teletypes with electronic stunt boxes and buffering to allow them to operate at line speeds greater than 75 bps, and,

c. New ANSI consistent terminals capable of operating at line speeds greater than 75 bps.

In the design process, either modified terminals or new terminals are assumed appropriate for locations having traffic in excess of 16 KCHR/HR. This assumption is based on the detailed analysis presented in the Telcom Report on Service B modernization and discussions with FAA personnel on the relation of operator efficiency to terminal type. Because terminal changeover will be based on these factors, the cost associated with the changes will not affect the design process. Consequently, no attempt is made here to associate a cost with each of the alternatives.

F.3 MODEMS

Both computers and terminals supply and accept information in the form of a digital baseband signal. A voice-grade line (type 3002) may be roughly characterized as having useable bandwidth extending from 300 Hz to 3000 Hz (-3 to +12 dB variation - Bell System Technical Reference PUB 41004). The function of the modem (modulator-demodulator) is to interface the digital baseband requirement to the analogue bandpass requirement, as shown in Figure F-1. A variety of techniques may be used to accomplish the interfacing, giving rise to an extraordinary range of modem cost and performance characteristics. Table F-1 shows typical purchase prices based on a survey of commercially available modems. Also shown are monthly costs based on amortization at 10% for ten years, plus a monthly maintenance cost of 1% of the purchase price.

It should be noted that at speeds up to 1200 bps almost all modems operate in an asynchronous mode using FSK (Frequency Shift Keying) techniques. Above this rate synchronous modes of operation prevail with the complexity and cost of the equipment being almost directly dependent on the line speed selected. Modems which operate at 4800 bps and 9600 bps usually require C2 line conditioning.

In this design process, all modems are assumed to have dial-up backup at an additional cost of $11/month.

F.4 MULTIPLEXERS

The term "facility" is used to refer to the part of the telephone plant described in terms of its properties as a transmission medium; the term "channel" is used to refer to a functional communications path. A channel is described by its capacity, i.e., the maximum rate at which information can be acceptably transferred over it. A channel for the transfer of digital data is formed by placing a modem at each end of

a facility. The capacity of the channel, the maximum data rate acceptable, depends on a variety of factors, including the bandwidth of the facility and the hardware characteristics of the modems. The use of one facility to form several separate channels is called multiplexing. A device which combines multiple facilities, each used for one or more distinct channels into one facility formed into the same distinct channels, is called a multiplexer. A device performing the reverse process, i.e., transforming one facility formed into several channels into multiple facilities, each with one or more of the channels, is called a demultiplexer. Many current hardware devices perform multiplexing in one direction, and demultiplexing in the other direction. Such a device is usually simply called a multiplexer.

The channel is the functional communications path, whereas the facility is part of the hardware used to form a channel. A multiplexer does not alter the channel structure of the network, thus is functionally transparent. However, the physical facilities from which channels are formed determine a large part of network costs. Multiplexing offers a way to achieve significant economies in facilities use.

Two basic multiplexing techniques are available: FDM (Frequency Division Multiplexing) and TDM (Time Division Multiplexing). These two techniques and associated costs are briefly described below.

F.4.1 Frequency Division Multiplexing

The FDM approach is to divide the bandwidth of the facility into several separate segments and allow each segment to serve a separate channel. This is graphically portrayed in Figure F-2. This class of multiplexers when used over type 3002 facilities has a maximum effective transmission rate of approximately 1800 bps. This capacity will

support a maximum of 24 75-bps-channels. At a 300 bps rate the line limits the number to 6. However, the maximum number of 75 bps channels supported by a particular multiplexer may be more or less than this number according to the particular device, the associated coding and signalling techniques, and confidence in telephone line conditioning.

The cost factors range from $290/FDX channel end (based on an 8-channel package) to $667 for a one-channel FDX package. An estimating figure of $400 per channel-end appears appropriate.

The upper limit on subscribers and the inefficiency of line utilization are arguments against FDM, while cost and simplicity are the positive points. Each channel has a simple modem. There is no need for high-speed modems, therefore no additional costs.

As the basic unit of signalling is the bit, the code character structure is of no importance to the FDM, only the users.

Any mix of speeds which are supportable on a given multiplexer may be used. The only limitation is the bandwidth of the line and sub-channel allocations.

A principal feature of FDM is its ability to have a single sub-channel easily multipointed at different locations. This allows a single voice-grade multipoint facility to provide several multipoint low-speed channels. However, because most of the locations to be served by NADIN have only one terminal to be included in the initial phase, this feature of FDM is of little use.

F.4.2 Time Division Multiplexers

The TDM approach is to establish a high speed data stream over the facility and assign periodic time slots, or bit positions, of the data stream to separate channels. This is graphically portrayed in Figure F-3. There are several variations on the implementation of this approach. Two fundamental variations are bit versus character interleaving, each being generally capable of handling all 5-8 bit/character codes with attendant start/stop bits.

Most TD multiplexers for voice grade facilities use modems in the range of 1200 bps to 9600 bps to establish the high speed data stream. The selected speed need only be greater than the sum of the speeds of the channels being multiplexed. The maximum number of subscribers supported at a given input rate varies with device structure, with some devices limiting the mix of speeds through the multiplexer/ e.g., 75, 110, and 150 bps. However, due to the relatively few standard signalling speeds used for low-speed asynchronous terminals, even the most severe limiting is not a major area of concern.

Error detection is almost universally provided for control signals. However, automatic parity on data characters is available on only a few and then is an option on all but one device studied. If parity is included in the data character, it is of course passed but not checked.

The logic circuitry required for TDM gives a TD multiplexer a different cost structure than is the case for FDM. A purchase price of $1500 plus $150 per channel per station is typical. A high speed modem is also required for each station. A redundant common logic TDM unit has a typical price of $2500 plus $150 per channel. With amortization and maintenance, this gives a cost of $67/month plus $4/month per channel.

TD multiplexing has an intrinsic advantage over FDM in its ability to utilize the voice grade facility bandwidth more completely via a high speed modem. However, its requirement for high speed line synchronization prohibits it from being effectively used to drop multiple channels at several different locations, as can be done with FDM. Because this is not a current requirement in NADIN, TDM is advantageous for NADIN in comparison to FDM.

F.5 CONCENTRATORS

The word "concentration" appears to have a very broad and ambiguous meaning in data communications. In this section, a concentrator, as envisioned for possible use in NADIN, is described in terms of its general function of "concentration" and in terms of its specific functions in NADIN.

F.5.1 General Function of Concentrator

Consider a device having several facilities connected to its input and only one facility connected to its output. At this point the device may be a multiplexer. However, it is distinguished by the following characteristic: the single facility on the output side carries one channel, the capacity of which is less than the sum of all the capacities on its input side. Such a device providing effective communications is called a concentrator. A multiplexer is transparent to the channel structure of a network; a concentrator obviously is not.

The percent of time a channel is used is called its utilization. Many terminals generate data for transmission at an average rate which is much less than the capacity of the channel resulting in channels with low utilization. A concentrator achieves economic advantage by replacing several low utilization channels with one highly utilized channel.

A prerequisite for a concentrator is that its output channel capacity be greater than the sum of the average data rates of the terminals on its input. It is at this point perhaps helpful to examine the difference between a multiplexer and a concentrator in more detail.

To each time slot of each channel on the input of a TDM, a time slot is assigned in the high capacity channel on its output. This effectively divides the high capacity output channel into several separate subchannels, each associated with a particular channel on the input. It does not matter whether or not a time slot is being used to transfer information. A concentrator has more time slots arriving on its input side than leaving on its output side. Each time slot carrying information must be assigned a time slot on the output side. Thus a concentrator must be able to identify which time slots are in fact transferring information. Furthermore, it must be able to assign output time slots to this information in such a manner as to be understood by whatever device is on the other end of the output channel. Although the average number of time slots carrying information on the input will be less than the number available on the output, over a brief interval the randum nature of terminal use may result in the number of arriving slots carrying information being greater than the number of slots available on the output. Hence, the concentrator must also have the ability to buffer the arriving information as it waits for available slots. The requirements of intelligence and storage for a concentrator invariably lead to its implementation with a minicomputer. The actual operation of concentrators varies considerably, but is usually much more complicated than the simple bit packing noted above. By performing such local operations as polling, error checking, line control, etc., and transferring

information to the computer with efficient high speed transmission techniques, the concentrator can achieve an apparent output channel utilization in excess of 100 percent.

The performance of these tasks also considerably reduces the requirements for the central switch. Thus, the general function of the concentrator is to reduce line costs by better facility utilization, and to off-load the central switch by performing several of the communications tasks.

F.5.2 Functions of Concentrator for NADIN

A concentrator may be used in NADIN for the basic reasons described in the previous section. In particular, the concentrator would provide a means of locally terminating several low speed channels and transferring the messages to a central switch over one voice grade channel, thus reducing line costs and trading concentrator I/O port costs for central switch port costs. In addition, the concentrator would perform the polling of the local circuits, thus reducing the processing load on the central switches. The concentrator would also provide a convenient and efficient means of interfacing with the NAS 9020 computers where collocated.

A particular advantage to the use of concentrators is the effective establishment of a high-speed data transfer backbone that can initially be tailored in size for the initial NADIN requirements, but structured to grow easily with increasing requirements.

Concentrators are almost invariably implemented with minicomputers, giving them a degree of intelligence and, consequently, flexibility. The intelligence could easily be used to perform the message switching appropriate for local intercircuit traffic, thus further reducing the processing requirements of the central switch. However, to keep concentrator reliability high and cost low, the concentrator

should not have any journaling tasks requiring auxiliary storage, such as a disk. Thus, whether or not local switching should be performed should be decided on the basis of whether or not journaling is to be required. The cost impact of switching (without journaling) should be very small, and is appraised below. In either case, the concentrator will accumulate statistics regarding network performance, traffic, and reliability.

F.5.3 Cost of Concentrator

The cost of a concentrator depends on three major variables:

1. Number of line terminations,
2. Traffic volume,
3. Extent of processing requirement.

Typically a basic 16 bit minicomputer with 8,000 words of memory costs from $4,000 to $10,000. A wide variety of architectures is available, having different I/O structures and expandability characteristics. Line interfacing depends on both the I/O structure and tradeoffs of processing power useage versus hardware capability. A survey of the more popular machines being used as concentrators reveals a cost range of $200 to $500 per low speed line. High speed lines usually require somewhat more complex interfaces, at a typical cost of $1,000 per line.

The second major cost variable is traffic volume, affecting the needed memory capacity, memory speed, and processing power. In recent years, memory costs have been substantially reduced from the long time standard of a dollar per word, to a point where memory is now available in some minicomputers at a cost of less than 25¢ per word. Memory cycle time has been reduced to less than one microsecond and

several vendors offer microprogrammed machines tailored for communications. However, these factors tend to balance out in overall system costs, with such factors as memory speed being directly related to memory cost.

The third significant cost factor is a function of the amount of processing to be done on the messages by the concentrator. The cost impact for processing is twofold. First is the cost of the software itself and second is the cost for the additional core required for storage of the programs and data. Thus, the addition of the switching function to a concentrator should be expected to increase its cost somewhat. However, because memory comes in discrete size packages and the processing required for the switching is quite nominal in comparison to the message storage requirements and other software requirements, there is no significant impact on the concentrator cost for switching.

Several vendors offer communication software packages with their minicomputers. However, none will be completely acceptable as a turnkey system for the NADIN requirements. The software development cost to convert the concentrator package to satisfy NADIN requirements is estimated as approximately $200,000.

A particular attribute of concentrators which adds significantly to their attractiveness for NADIN is their potential expansion to serve additional requirements. Thus, in the cost estimate developed below, care was given to base costs on the available machines which have advanced architectures capable of easy expansion and are offered by established vendors which may be expected to support continued enhancement of their product.

The concentrator cost estimate is expressed in terms of a basic machine cost plus cost for each low speed line interface. The basic machine cost includes 16K words (16 bit) memory, two synchronous line interfaces, real-time clock, memory protect, power-fail protection, and software costs assuming a twenty concentrator design.

Concentrator Cost:

$24,000 + $350/low speed line.

Ten year amortization at 10%, plus 1% purchase price per month for maintenance, plus a TDM multiplexer at each concentrator for reliability (as discussed in Appendix E), gives a monthly cost of:

Concentrator Cost ($/Mo.):

$680 + $13/low speed line.

F.6 MESSAGE SWITCH

The term "message switch" refers to a communications processor which receives, routes, and forwards messages. With this broad definition, concentrators which perform local switching are message switches. However, the meaning intended here is considerably more precise. A message switch in NADIN will have the facilities necessary for journaling, network management, operator interaction, interface with other networks, etc. In general, a message switch in NADIN is characterized as being an intelligent center responsible for the overall coordinated operation of the network. There are three basic categories of message switches that might appear in NADIN:

Category 1: Those appropriate for terminating a large number of polled multipoint lines, i.e., switches appropriate for use in the CONUS when concentrators are not used.

Category 2: Those appropriate for terminating a small number of point-to-point medium speed lines, i.e., switches appropriate for use in the CONUS when concentrators are used.

Category 3: Those appropriate for terminating a small number of polled multipoint lines, i.e., switches appropriate for use in Alaska and Hawaii.

A detailed discussion of the costs of the various switching configurations is beyond the scope of this study. However, in order to develop a cost appraisal of the various architectural alternatives, it is necessary to estimate the cost of the switching configurations implied by the different architectures. The estimates given below are based on satisfaction of the NADIN throughput requirements with processing delays negligible in comparison to the basic communication delays as described in Appendix D. The estimates assume high quality equipment from established vendors who are capable of providing continued hardware and software support and they include the software costs of tailoring existing packages to NADIN requirements plus installation on a turnkey basis. The estimates were achieved from a survey of equipment currently available from vendors and the estimated costs have been adjusted to reflect uncertainties in the inputs.

Category 1: $700,000

Category 2: $400,000

Category 3: $360,000

Amortization over ten years at 10%, plus 1% purchase price per month for maintenance, gives a monthly cost of:

Category 1: $18,662/month

Category 2: $10,664/month

Category 3: $ 9,598/month

Transmission Rate (bps)	Purchase Price	Amortized Cost ($/Mo.) Plus 1% Maintenance
75	$ 500	13.33
110	500	13.33
150	500	13.33
300	500	13.33
600	500	13.33
1,200	500	13.33
1,800	750	20.00
2,000	1,780	47.45
2,400	1,780	47.45
3,600	3,620	96.51
4,800	4,800	127.97
7,200	7,200	191.95
9,600	9,750	259.94

TABLE F-1: TYPICAL MODEM COSTS

APPENDIX G

MESSAGE FORMATS

G.1 INTRODUCTION

In combining existing autonomous networks, it is inevitable that adjustments be made to communications methods, procedures and formats. Ideally, the adjustments should minimize the impact on the user and on the communications operator in that order. These adjustments are especially important in the integration of AFTN and Service B in order to preclude disruption of service and to utilize installed terminal equipment as fully as may be cost effective.

The objective of this appendix is to present a NADIN message format and show how Service B and AFTN users are isolated from transition effects to this new format by the NADIN concentrators.

G.1.1 Design of a Message Communication System

Communications methods, procedures and formats manifest themselves in a message-oriented communications system as link control, network control, and communications message control information which are added to and deleted from the users text as the message progresses through the network. The designer of a communication system must understand these functions and balance the use of elaborate control techniques and their inherent overhead against the users'needs, the network architecture and cost.

G.1.2 Communication Control Envelopes

The communications control information needed to pass a message through a network may be represented by a series of information envelopes. These envelopes form a natural hierarchy as seen in Figure G-1. A major consideration for the

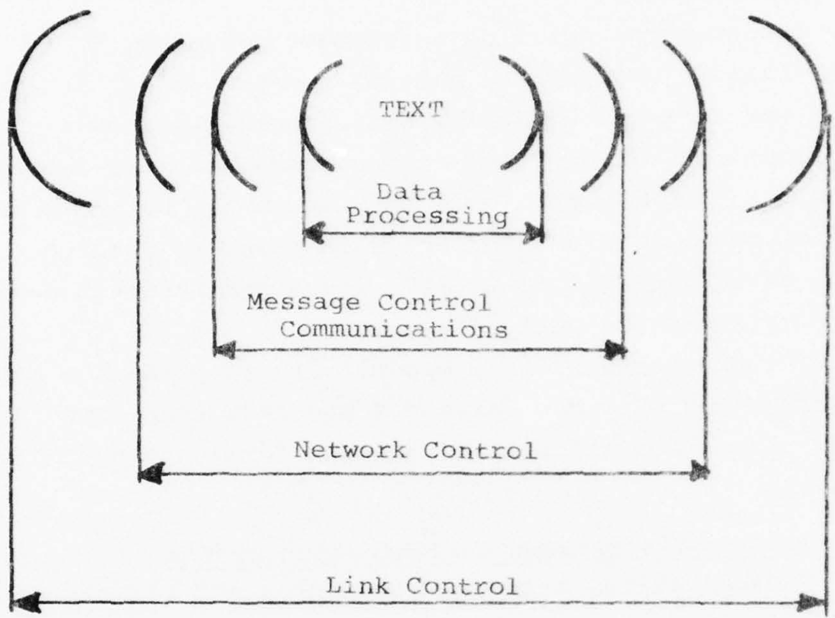


Figure G-1

Figure G-1 HIERARCHY OF MESSAGE ENVELOPE

system designer is to be able to delineate the starting and ending points of each envelope, especially when the processing of these envelopes is typically performed by a communications processor.

G.1.2.1 Link Control

The Link Control envelope contains information needed to support link establishment, link termination and message transfer control procedures. These procedures must be suitable for multi-point, point-to-point and multi-channel links; they frequently are adapted to classes of terminal equipment, in which each class represents degrees of terminal complexity and capability; and, theoretically, the link control envelope should contain information only pertinent to the link being entered. In practice, the purity of this concept is not always maintained. Ideally, a link control envelope is built and discarded for each link. In practice this usually is done, but occasionally information contained in the link control envelope is passed on to succeeding links.

G.1.2.2 Network Control

The network control envelope contains information needed to support the network routing process. Frequently it is added at the entry node to the network and removed at the exit node. Thus, users are frequently not concerned or even aware of its existence. It can be considered a tool of the communicator.

G.1.2.3 Communications Message Control

The communications message control envelope contains information required by the communicator to accept a message from the originator and deliver it to the addressee. Though this information is for the communicator, it frequently is contained on the addressee's copy. Many addressees erroneously

rely on this information for internal use. When communicators change procedures - altering or eliminating this information from the addressee's copy - they may receive unexpected complaints from the network users.

G.1.2.4 Data Processing Control

The data processing control envelope contains information needed to bridge the interface between communications processing and data processing. It may contain message type, file identification, privacy information, etc. Its use is becoming increasingly common, especially in applications where the communications processor serves as a front end to a data processor.

G.2 PROPOSED MESSAGE FORMAT FOR NADIN

The FAA asked Telcom to develop a NADIN message format in ICAO-7 code useable in a large variety of situations, including:

a. Operator-generated messages,
b. Computer-generated messages,
c. Point-to-point links,
d. Multi-point links,
e. Simple terminals, e.g., teletypewriter,
f. Complex terminals with extended capabilities, i.e., "intelligent" terminals,
g. Messages generated for human consumption,
h. Messages generated for machine consumption.

Additionally, the NADIN message format must be machine convertible to an AFTN message format in ITA-2 code.

G.2.1 Design Considerations

The format chosen for NADIN must meet a number of design objectives. These design objectives include:

a. The format must be flexible. This allows for changes in practices and procedures and allows for additional information to be added. Implementation provides the test facility for close examination of a message format and frequently, from the resulting experience, message format changes are recommended. The proposed format meets the flexibility objective by being modularly expansible and expansible within modules.

b. The message format must be readily understandable by a communications processing device. For efficient processing the format should be clearly demarked, each element therein clearly delineated, and the interpretation literal - no subjective decision.

c. The message format must be readily understandable by a communications operator. The message format must be easily prepared by a communications operator in those applications where manual preparation, even with terminal assistance, is envisioned. The message format must be readable and understandable by a communications operator to permit manual handling of a NADIN message, e.g., forwarding, servicing, retrieving, etc. This requirement on the NADIN proposed message format avoids the concept of data compression for NADIN. Telcom bases this recommendation on the belief that through most of the time period encompassed by the implementation of NADIN, the majority of the message traffic will continue to be prepared by and oriented to operators. As this process shifts to the bulk of the traffic being prepared by computers, handled by computers and directed to computers - a non-operator-oriented system - the FAA should consider, design and implement a computer-oriented format using modern techniques of data compression. The implementation of a computer-oriented format requires a computer or intelligent terminal to translate it to an operator-readable format.

d. The message format must not interfere with any of the other control envelopes. This objective is of course quite basic in any communications system. The start and end of each envelope must be uniquely distinguishable. This is obtained by a combination of unique characters and position-sensitive characters within the message format.

G.2.2 Message Format Structure

The basic message structure proposed for NADIN implementation is devoid of any link control information. The particular link control information selected by the FAA should be adapted to the needs of the link in question. This does not imply an unmanageable number of link control envelopes, but does suggest that there be several allowable combinations. The communications message envelope is divided for discussion purposes into its customary components of header, text, and end. It should be noted that a line shall consist of not more than 69 characters. The message format is shown in Table G-1 and the control characters explained in Table G-2.

G.2.2.1 Message Heading

The message heading is delineated by the Start of Header Signal, SOH, 0/1 and encompasses all information up to and including the Start of Text Signal, STX, 0/2.

The message heading is composed of two parts: the first part is called the destination and may consist of one or more lines; the second part is called the origin and consist of one line plus the STX signal.

G.2.2.1.1 Destination Line(s)

The destination line(s) compose the first part of the header.

TABLE G-1 NADIN MESSAGE FORMAT

Component of the Message Part	Elements of the Component	Teletypewriter Signal
Start of Message Signal	One character position 0/1	S O H
Priority Category	The relevant 2-letter group	A,A
Address Indicator(s)	One space, followed by 3, 6, or 8 letter groups. If more than one line is required, the alignment function shall be used.	Δ A_2 A_3 A_4 Δ A_5 A_6 etc.
End of Address Indicator	Period 2/14	. (period)
Alignment Function	One carriage return, one line feed	< ≡
Filing Time	7-digit date-time group specifying when the message was filed for transmission	D D D H H M M
Originator Indicator	a) One space b) 3, 6, or 8-letter group identifying the message originator	A_8 A_9 A_{10} A_{11} A_{12}
Optional Heading Information	Additional data not to exceed the remainder of the line	
Alignment Function	One carriage return, one line feed	< ≡
Start of Text	One character position 0/2	S T X
Message Type Text Separator	Any character except excluded communications control characters	- (dash)
End of Text	One character position 0/3	E T X
Additional Communication Information (Optional)	Additional data may exceed one line	
Alignment Function (Optional)	One carriage return, one line feed	< ≡
End of Transmission	One character position 0/4	E O T

TABLE G-2

Control Character Symbols and Meanings

Symbol	Meaning
≡	line feed
< or ←	carriage return
↓	letters shift
↑	figures shift
→ or Δ	space
b̸	blank
A_1, A_2, etc.	any alphabetic character
N_1, N_2, etc.	any numeral
A, B, etc.	the actual character shown
DD	numerals indicating day of the month
DDD	numerals indicating Julian day
HH	numerals indicating hour of the day
MM	numerals indicating minutes past the hour
* (N) *	N repetitions of the character *
SOH or S O H	beginning of message; character position
STX or S T X	beginning of text; character position 0/2
ETX or E T X	end of text; character position 0/3
EOT or E O T	end of message; character position 0/4

Character position designations are in accordance with the ICAO-7 character set.

AD-A040 315 TELCOM INC VIENNA VA F/G 17/2
NETWORK ARCHITECTURE OF NATIONAL AIRSPACE DATA INTERCHANGE NETW--ETC(U)
OCT 75 DOT-FA74WA-3264
UNCLASSIFIED FAA-RD-74-200 NL

4 OF 4
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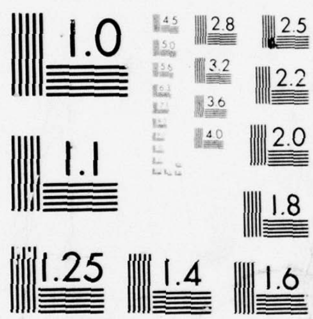

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

G.2.2.1.1.1 Start of Header Signal

The start of header signal (also start of message) is the ICAO-7 communications control signal "SOH", 0/1. It is the beginning delineator of the message envelope. All information before this character is not part of the permanent communications record of the message. Other than serving as a delineator, this character performs no function.

G.2.2.1.1.2 Priority Indicator

The priority indicator consists of the relevant two-letter group. A discussion in some detail of priority indicators in the NADIN system is contained in Paragraph 5 of this appendix.

G.2.2.1.1.3 Address Indicator(s)

The address indicator consists of one space, followed by 3, 6, or 8 letter groups. For a detailed discussion of address indicators see Paragraph 6 of this appendix and Section 8 of the main body of this report. There is no specific limit to the number of addresses permitted; however, some reasonable number should be imposed on the communications system by procedure. If the number of addresses in a line exceeds 69 characters, the addresses must be broken at an address indicator group and followed by the alignment function, one carriage return and one line feed.

G.2.2.1.1.4 End of Address Indicator

The end of address indicator is the graphic character "period", ICAO-7 signal 2/14. The end of address indicator terminates the list of addressees. It is not a unique character, of course, but is position locatable in that it is the first "period" character in the heading after SOH.

G.2.2.1.1.5 Alignment Function

The alignment function consists of one carriage return and one line feed, ICAO-7 signals 0/13 and 0/10. Together with the end of address indicator, it terminates the Destination Part of the communications message header.

G.2.2.1.2 Origin Line

The origin line is bounded by the end of address indicator plus alignment function and by the next occurring alignment function. Thus it cannot exceed 69 characters.

G.2.2.1.2.1 Filing Time

The filing time consists of seven digits representing the Julian day and time. It specifies when the message was filed for transmission.

G.2.2.1.2.2 Originator Indicator

The originator indicator identifies the message originator. It consists of one space and a 3, 6, or 8-letter group.

G.2.2.1.2.3 Operational Heading Information

This consists of additional data not to exceed the remainder of the line. It should be limited to communications information. Information found in this section of a message may include special servicing information, communications accounting information, etc.

G.2.2.2 Message Text

The text of a message consists of all the information contained after the communications control character STX and before the communications control character ETX. It contains the information that the originator of the message wishes conveyed to the addressee. It may contain information

added by data processing, e.g., file number, message type, etc. It may also contain information added by the communications office responsible for filing the message, e.g., repeat of numerical information, corrections to errors in text caused by the communications office filing the message, etc.

G.2.2.2.1 Information Processing

Except for these few examples, the communicator was customarily forbidden to operate on the message text. With the advent of data processing and the implementation of data communications processing the boundaries of responsibility became blurred. A broader perspective of the system known as information processing developed. From the information system analyst's viewpoint, envelopes, processing responsibility, etc., belong to the entity best suited to perform that function in an automated environment. The front-end to a large scale data processor is a good example of a processor performing mostly communications functions as well as performing some data processing functions, e.g., preliminary edits, sorting to functional files, etc. The functional divisions of information processing vary from application to application. As an example, in applications where error detection is used but error correction is not, the communication processor upon receipt of a character in error might: (1) change it to a special character, or, (2) ignore the error. Application considerations such as the importance of data integrity, alpha versus numeric, machine versus human consumption, etc., are factors that would effect the decision.

G.2.2.2.2 NADIN Data Processing Envelope

To accommodate anticipated requirements, Telcom recommends the inclusion of a data processing envelope. The data processing envelope should be delineated by the communications control character STX and by the first alignment

function following the STX. Telcom suggests that the first field in the DP envelope be the message type analogous to field 01 in the current NAS Stage A message entry format.

G.2.2.3 Message Ender

There is no universal practice among communication systems as to what functions belong in a message ender. Surveying a variety of message enders, one might find end of text separator, end of message separator, link control information, device control information, format control information, message accountability information, etc. Complicating the situation is the practicability of selecting delineators that are identifiable and do not interfere with link or device control procedures. Further limitations may result from the information alphabet. For example, the ICAO-7 alphabet provides for a standard End of Text delineator via the use of the communications control character ETX,0/3. However, no provision is made for unique End of Message delineator in the ICAO-7 alphabet.

G.2.2.3.1 Alignment Function

The alignment function of carriage return (CR) and line feed (LF) shall follow the last character of text.

G.2.2.3.2 End of Text

The end of text is the ICAO-7 communications control character "ETX", 0/3. Other information may follow this character but any such subsequent information shall only contain communication information.

G.2.2.3.3 Additional Communication Information

This is an optional element in the message format and may not exceed one line length. Typical uses might include accounting information, message accountability, etc.

G.2.2.3.4 Alignment Function

The alignment function of carriage return (CR) and line feed (LF) shall follow the last character of the Additional Communication Information.

G.2.2.3.5 End of Transmission

The end of transmission is signified by the ICAO-7 communications control character "EOT", 0/4. This character also implies end of message. No Characters, not even device control characters, may follow the EOT signal.

G.3 LINK AND DEVICE CONTROL ENVELOPE

In this appendix, the distinction between the message envelope with its elements of information and the link control envelope has been emphasized. To complete a typical message exchange, one uses a recognized method of link establishment and termination procedure and message exchange procedure. Frequently, imbedded within the link control information is device control information.

G.3.1 Link Control

Because of the factors discussed in Appendix A, more than one link control procedure must be utilized in NADIN. It must be the responsibility of the NADIN message switches and concentrators to build the proper link control envelope and mesh it with the message envelope.

G.3.2 Device Control

Device control information is, of course, a function of the terminal presently in communication with the controller. Typical functions performed by device control information include turning equipment on or off, selecting equipment at a multi-media terminal, selecting operator alarms, line and page alignment, tape feed for a ROTR, timing delays

for carriage return or other mechanical functions, etc. Again, it must be the responsibility of the NADIN message switches and concentrators to provide the proper device control information.

G.3.3 MESSAGE ACCOUNTABILITY

A variety of techniques and procedures have been used to verify that communications links were in order (monitoring and channel continuity checks), and to verify that all messages transmitted over a link were, in fact, received by the receiving terminal. These latter procedures are generally referred to as message accountability procedures.

G.3.3.1 Message Numbering

A method commonly employed is sequential numbering of each message. Any interruption in the numbering sequence requires the recipient to inquire of (service) the transmitting station. This procedure can be implemented either manually or automatically. The present AFTN teletypewriter procedures incorporate this method of message accountability. On multipoint levels, message sequencing may also be used if accountability is maintained at a station level. This is typically accomplished by all stations monitoring the "top line", which contains the channel sequence number or by maintaining and transmitting individual station sequence numbers to each message. The latter technique is practical when the accounting is performed by a communications processor.

Generally the message numbering starts at 001 and runs to 999 or 9999 upon which it is recycled to 001. The numbers are usually recycled at the beginning of the day (0000) using local time or GMT. This method of message accountability is universally accepted and quite practical to implement providing the total number of messages exchanged on a daily basis is less than 10,000.

G.3.3.2 Automated Message Exchange

For circuits operating at medium speed, the potential daily message capacity is in the hundred thousands for NADIN applications. Many medium speed link protocols have built-in message accountability provisions, e.g., automatic message acknowledgement, precluding the necessity for traditional message sequencing. Using the ICAO-7 alphabet, a 2400 bps circuit has a theoretical throughput of 300 characters per seconds (CPS). Well designed, full duplex, continuous transmission with simultaneous supervision, synchronous link control procedures can attain efficiencies of 80% of the theoretical throughput.

Thus, the effective information throughput can be 240 cps. This is approximately equal to two (2) NADIN messages per second. Therefore, in one day, a link operating at 2400 bps could transfer 172,800 typical NADIN messages.

Telcom recommends selecting the message accountability procedures that match the requirements of the link. Where the message exchange provisions of the link protocol meet FAA requirements for message accountability, there is no need to impose additional overhead on the message transfer procedures. For links utilizing less comprehensive procedures, the continued use of message numbering on a circuit or station basis is in order.

G.3.3.3 Message Sequence Numbering in the NADIN

To illustrate the application of message sequence numbering in the NADIN system, the message format proposed in paragraph G.2.2 of this Appendix must have added to it a link control envelope. For brevity purposes, establishment, device control, polling, and termination sequences are not shown.

The following example illustrates message sequence numbering on a channel basis.

<u>SOH</u> A_1 A_2 A_3 N_1 N_2 N_3 < ≡

Destination Line

Etc.

<u>ETX</u>

<u>EOT</u>

where $A_1A_2A_3$ is the transmitting identifier and $N_1N_2N_3$ is the channel sequence number. The same effect can be obtained by placing the message sequence number after the ETX as shown below.

<u>SOH</u> Destination Line

Etc.

<u>ETX</u> A_1 A_2 A_3 N_1 N_2 N_3

<u>EOT</u>

For links where station message sequencing is desired, the message accounting information should be attached as follows:

<u>SOH</u> $A_1A_2A_3$ $N_1N_2N_3$ Δ $A_4A_5A_6$ $N_4N_5N_6$ Δ $A_7A_8A_9$ $N_7N_8N_9$ < ≡

Destination Line

Etc.

<u>ETX</u>

<u>EOT</u>

or

<u>SOH</u> Destination Line

Etc.

ETX $A_1A_2A_3$ $N_1N_2N_3$ Δ $A_4A_5A_6$ $N_4N_5N_6$ Δ $A_7A_8A_9$ $N_7N_8N_9$ < ≡

Note that the link control procedure resolves the end of the numbering sequence by the termination sequence, EOT.

The particular method and format employed must be configured to match the link control requirements. This does not imply that an unmanageably large number of formats is recommended; rather, the formats must constitute a compatible family, but limited in number.

G.4 CODE AND FORMAT CONVERSION

The following paragraphs illustrate the principles of code and format conversion developed in the preceding paragraphs of this appendix. They illustrate messages arriving from specific devices on specific links and being forwarded to specific devices on specific links as described in the limiting notes attendant with each illustration. The examples do not show potential benefits that can be derived from computer assisted formatting. Therefore, these examples illustrate the aforementioned principles and are not intended to be the final recommended procedures by line and terminal class.

G.4.1 Service B to NADIN

The following examples illustrate messages originating from a Service B terminal. The terminal is polled by a NADIN concentrator.

Poll: $\equiv < \downarrow A_1A_2 \rightarrow\rightarrow$

Response: $< < \downarrow A_1A_2A_3 < < \equiv$

$\mathrm{ZCZC} \rightarrow \mathrm{ABA053} < < \equiv$

$\mathrm{FF} \rightarrow A_1A_2A_3 \rightarrow \mathrm{BBB} \rightarrow \mathrm{CCCCCC} << \equiv$

$1012345 \rightarrow \mathrm{XXXXYY} << \equiv$

Text

↓ << ≡ (EOT)

NNNN (EOM)

The above is an example of a message to one station on the same circuit and two stations not on same circuit using non-centralized control.

Poll: ≡ < ↓ A_1A_2 →→

Response: ZCZC → ABA053 << ≡

FF → $A_1A_2A_3$ → BBB → CCCCCC << ≡

1012345 → XXXYY << ≡

Text

↓ << ≡

NNNN

The above is an example of a message to one station on the same circuit and two stations not on same circuit using centralized control.

In both of the above examples, the messages are destined to Service B and AFTN terminals.

G.4.2 <u>NADIN to Service B</u>

The following examples illustrate a message from the NADIN network being delivered to a Service B terminal. The terminal is called by a NADIN concentrator.

Call: << ↓ $A_1A_2A_3$ << ≡

ZCZC → XYZ076 << ≡

FF → $A_1A_2A_3$ << ≡

1012345 → XXXYY << ≡

↓ << ≡

(7) ≡ NNNN

The above is an example of a message to one station on a circuit with channel sequence numbers.

G.4.3 AFTN to NADIN

As noted in Appendix A, the AFTN format will not be affected by NADIN procedures. The following example illustrates a message originating from an AFTN terminal. The terminal is polled by the NADIN concentrator.

Poll: A_1A_2

Response: < ≡ ↓ ZCZC → ABC 123 << ≡

FF → AAAAA << ≡

201234 → BBBBBB << ≡

Text

↓ << ≡ (7) ≡ NNNN

G.4.4 NADIN to AFTN

NADIN will deliver messages to the AFTN network. The following example illustrates a message from NADIN being introduced into the AFTN network. It should be noted that this example is of proper format and content; however, the detailed design of format conversion must provide for mutilated message formats, no enders, etc.

Call: A_1A_2

Response: V

Concentrator: < ≡ ↓ ZCZC → XYZ 456 < < ≡

FF → AAAAAA

171234 → BBBBBB < ≡

Text

↓ << ≡ (7) ≡ NNNN

G.5.0 PRIORITY

G.5.1 General

The present AFTN procedures provide for seven priority indicators and six levels of order of priority transmission. The order of priority for transmission of messages is:

1. SS
2. DD
3. FF
4. GG
5. JJ and KK
6. LL

The present Service B procedures recognize the ICAO priority indicators, and also the four precedence levels used in the National Communication System (NCS). NCS and ICAO indicators are related as shown in the following Table:

ICAO	NCS	
1. SS	Flash	(Z)
2. DD	Immediate	(D)
3. FF	Priority	(P)
4. GG and JJ	Routine	(R)

The proposed CIDIN procedures show only two priorities for network trunks.

G.5.2 NADIN Priority Requirements

NADIN messages may be divided into two classes, each with its own demand for priorities. The classes are:

- Information Transfer - no immediate reply.
- Information Transfer - immediate reply.

The first class, information transfer - no reply, contains the preponderance of all existing Service B messages and all AFTN messages. The basic characteristic of this class of messages is that no reply is expected or, if there is to be

a reply, the response time of the reply is not significant. The second class of messages are distinguishable in that a reply is expected and the response time for the reply is relatively short (real-time or near real-time). This class of traffic may currently be found on Computer B circuits.

G.5.2.1 Response Time vs Priorities

The priority indicators specified for use in AFTN and Service B have associated NCS defined message transfer times or network response times. These response times are for messages in the first class, i.e., information transfer with no immediate reply. The network response time for these messages ranges from minutes to hours.

To accomodate messages in the second class, network response times of a few seconds are required. No AFTN or Service B priorities categories exist to represent these response times. Fortunately, these messages are distinguishable by message type and presently are found only on Computer B links. As concluded in Telcom's previous study of Service B it is not recommended that real-time response traffic be imposed on a common-user message oriented network because of the resulting costs. Therefore, it may not be necessary to develop priority indicators for these message types.

G.6.0 ADDRESSING

AFTN addresses may be six-or eight-character groups. Service B addresses are three- or four-character groups. It is quite technically feasible to permit a mixing of address lengths. For the NADIN network, Telcom feels that there are no significant technical reasons precluding the mixing of address lengths. Furthermore, Telcom recommends the inclusion of a five character address to permit addressing to functional levels within the present Service B environment. A three character address would automatically result in a default

function at each specific location. This default function need not be the same at every location.

G.7 AUTOMATED ASSISTANCE TO TERMINALS

Switches, concentrators, and programmable terminals can be programmed to perform many functions that would otherwise be an additional burden to the operator and, in some cases, involve an unnecessary transmission of information. For example, certain terminals may invariably send messages to a small, fixed set of addressees; in such cases, the switch, recognizing the source of a message, could supply the addresses from stored tables, thus reducing the volume of the input traffic. Likewise, certain message types, regardless of origin, may always be destined to the same set of addressees, also permitting the switch to supply the actual addresses. Messages involving a relatively small amount of variable information embedded in a stereotyped text can be handled economically by transmitting only the variable portion and supplying the fixed portion at the destination concentrator or at the addressed terminal, if it is programmable. The NADIN architecture provides unlimited opportunities of this kind for increased economy of operation, in addition to the primary economies in network facilities.

APPENDIX H

SERVICE B TERMINALS

AREA NO. 1
ARTCC ZBW

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
BOS	BOSTON,MASS.	15.475	2.163	20.192	38.364	42.444	71.047
BDL	WINDSOR LOOKS,CONN.	6.835	7.716	9.094	17.278	41.872	72.766
UCA	UTICA,N.Y.	5.068	5.636	6.544	12.433	43.017	75.630
ALB	ALBANY,N.Y.	4.347	4.850	5.647	10.728	43.017	73.812
CON	CONCORD,N.H.	4.832	5.246	5.916	11.240	43.017	71.620
BGR	OLDTOWN,MAINE	4.526	4.857	5.397	10.254	44.736	68.755
MPV	MONTPELIER,VT.	3.063	3.275	3.630	6.898	44.163	72.766
AUG	AUGUSTA,MAINE	2.278	2.441	2.709	5.147	44.163	69.901
MSS	MASSENA,N.Y.	2.274	2.409	2.535	5.007	44.736	75.058
HUL	HOULTON,MAINE	1.923	1.950	2.019	3.436	45.882	67.609
LEB	LEBANON,N.H.	1.672	1.714	1.799	3.418	43.590	72.193
GFL	GLENS FALLS,N.Y.	1.380	1.408	1.470	2.793	43.590	73.339
ORH	WORCESTER,MASS.	1.322	1.342	1.396	2.653	42.444	71.620
ART	WATERTOWN,N.Y.	1.262	1.248	1.244	2.363	44.163	76.203
ZBW	BOSTON,MASS.	2.333	2.800	4.199	7.979	42.930	71.430

AREA NO. 2
ARTCC ZNY

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
ISP	ISLIP,N.Y.	23.057	26.639	32.209	61.197	40.726	73.339
PNE	PHILADELPHIA,PA.	12.263	13.940	16.555	31.454	40.153	75.058
TEB	TETERBORO,N.J.	11.319	12.824	15.182	28.945	40.726	73.912
MIV	MILLVILLE,N.J.	7.752	8.700	10.203	19.386	39.580	75.058
AVP	WILKES BARRE,PA.	5.592	6.276	7.360	13.984	41.299	75.630
HAR	HARRISBURG,PA.	4.539	4.991	5.717	10.963	40.153	76.776
ELM	ELMIRA,N.Y.	4.420	4.842	5.518	10.484	42.444	76.776
POU	POUGHKEEPSIE,N.Y.	3.311	3.619	4.111	7.812	41.872	73.912
SBY	SALISBURY,MD.	2.924	3.182	3.597	6.834	38.434	75.630
IPT	WILLIAMSPORT,PA.	2.108	2.255	2.503	4.756	41.299	76.776
PSB	PHILIPSBURG,PA.	1.578	1.641	1.757	3.339	40.726	77.922
ZNY	NEW YORK,N.Y.	2.333	2.800	4.199	7.979	40.770	73.100

AREA NO. 3
ARTCC ZDC

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
DCA	WASHINGTON,D.C.	22.321	25.459	30.346	57.658	39.007	76.776
PHF	NEWPORT NEWS,VA.	9.295	10.416	12.169	23.121	37.288	76.776
RDU	RALEIGH,N.C.	8.150	9.018	10.396	19.752	35.569	79.068
RIC	RICHMOND,VA.	4.676	5.136	5.874	11.160	37.288	77.349
RWI	ROCKY MONT,N.C.	4.678	5.156	5.909	11.226	36.142	77.922
EWN	NEW BERN,N.C.	4.265	4.595	5.128	9.742	34.996	76.776
MRB	MARTINSBURG,W.VA.	3.329	3.643	4.146	7.877	39.580	77.922
ROA	ROANOKE,VA.	3.156	3.359	3.698	7.027	37.288	80.214
CHO	CHARLOTTESVILLE,VA.	1.972	2.087	2.283	4.339	38.434	78.495
DAN	CANVILLE,VA.	1.426	1.463	1.532	2.[illegible]24	36.715	79.068
ECG	ELIZABETH CITY,N.C.	1.596	1.583	1.588	3.[illegible]18	36.142	76.203
EKN	ELKINS,W.VA.	1.[illegible]79	1.069	1.072	2.038	39.007	79.641
ZDC	WASHINGTON,D.C.	2.333	2.800	4.199	7.979	38.850	77.030

AREA NO. 4
, ARTCC ZJX

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
JAX	JACKSONVILLE,FLA.	8.740	9.907	11.727	22.282	30.412	81.933
CHS	CHARLESTON,S.C.	6.623	7.479	8.821	16.759	32.704	80.214
FLO	FLORENCE,S.C.	8.576	9.441	10.806	20.532	34.423	79.641
PNS	PENSACOLA,FLA.	5.635	6.287	7.310	13.989	30.412	87.090
SAV	SAVANNAH,GA.	6.176	6.785	7.743	14.712	32.131	81.360
TLH	TALLAHASSEE,FLA.	5.185	5.759	6.663	12.659	30.412	84.225
DHN	DOTHAN,ALA.	4.787	5.277	6.047	11.489	31.558	85.371
CEW	CRESTVIEW,FLA.	3.971	4.358	4.971	9.444	30.985	86.517
VLD	VALDOSTA,GA.	2.546	2.732	3.040	5.777	30.985	83.079
ABY	ALBANY,GA.	2.097	2.203	2.384	4.530	31.558	84.225
GNV	GAINESVILLE,FLA.	3.095	3.168	3.311	6.290	29.839	82.506
SSI	BRUNSWICK,GA.	2.119	2.211	2.371	4.505	30.985	81.360
AMG	ALMA,GA.	1.238	1.231	1.238	2.352	31.558	82.506
CRE		8.310	9.011	6.674	12.680	33.850	78.495
ZJX	JACKSONVILLE,FLA.	2.333	2.800	4.199	7.979	30.420	81.650

AREA NO. 5
ARTCC ZMA

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
MIA	MIAMI.FLA.	23.158	26.574	31.889	60.590	25.829	80.214
PIE	ST.PETERSBURG,FLA.	10.909	12.328	14.543	27.632	28.121	82.606
ORL	ORLANDO,FLA.	11.511	11.830	13.888	26.386	28.693	81.360
EYW	KEY WEST,FLA.	5.779	6.606	7.912	15.032	24.683	81.933
MLB	MELBOURNE.FLA.	4.162	4.579	5.236	9.949	28.121	80.787
FMY	FORT MYERS.FLA.	2.755	2.957	3.285	6.241	26.402	81.933
VRB	VERO BEACH.FLA.	3.479	3.640	3.898	7.407	27.548	80.214
TMA	MIAMI.FLORIDA	2.333	2.800	4.199	7.979	25.800	80.270

AREA NO. 6
ARTCC ZCV

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
BUF	BUFFALO,N.Y.	1[illegible].159	21.979	26.373	50.110	43.017	78.495
DET	DETROIT,MICH.	12.927	14.644	17.331	32.929	42.444	83.079
CLE	CLEVELAND,OHIO	1[illegible].790	12.176	14.348	27.261	41.299	81.933
AGC	PITTSBURG,PA.	[illegible].958	10.137	11.996	22.793	40.153	80.214
MBS	SAGINAW,MICH.	[illegible].553	5.097	5.956	11.317	43.590	84.225
FDY	FINDLAY,OHIO	3.811	5.224	6.029	11.455	41.299	83.652
YNG	YOUNGSTOWN,OHIO	3.[illegible]13	3.318	3.805	7.230	41.299	80.787
LAN	LANSING,MICH.	3.029	3.231	3.567	6.777	43.017	84.798
ERI	ERIE,PA.	2.[illegible]12	2.147	2.379	4.520	41.872	80.214
JXN	JACKSON,MICH.	2.389	2.5[illegible]4	2.709	5.147	42.444	84.225
AOO	ALTOONA,PA.	2.2[illegible]2	2.296	2.470	4.692	40.153	78.495
MGW	MORGANTOWN,W.VA.	2.242	2.372	2.591	4.922	39.580	79.641
C[illegible]H	MANSFIELD,OHIO	1.741	1.836	2.000	3.800	40.153	83.079
BFD	BRADFORD,PA.	1.566	1.631	1.750	3.325	41.872	78.495
HLG	WHEELING,W.VA.	1.469	1.5[illegible]3	1.574	2.990	40.153	80.787
DUJ	DUBOIS,PA.	1.343	1.370	1.434	2.724	41.299	79.068
ZCV	CLEVELAND,OHIO	[illegible].333	2.8[illegible]0	4.199	7.979	41.400	81.850

AREA NO. 7
ARTCC ZID

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
IND	INDIANAPOLIS.IND.	11.660	13.378	16.053	30.502	39.580	86.517
CMH	COLUMBUS,OHIO	10.351	11.818	14.105	26.800	40.153	83.079
DAY	DAYTON,OHIO	9.231	10.566	12.650	24.035	40.153	84.225
HUF	TERRE HAUTE.IND.	4.719	5.187	5.933	11.274	39.580	87.090
LUK	CINCINNATI.OHIO	4.403	4.850	5.566	10.576	39.007	84.225
LOU	LOUISVILLE.KY.	3.827	4.223	4.852	9.218	38.434	85.944
LOZ	LONDON,KY.	3.368	3.595	3.973	7.549	37.288	84.225
LAF	LAFAYETTE.IND.	3.017	3.255	3.641	6.918	40.726	87.090
CRW	CHARLESTON.W.VA.	2.743	2.912	3.198	6.076	38.434	81.360
BLF	BLUEFIELD.W.VA.	1.905	2.027	2.235	4.246	37.288	81.360
HTS	HUNTINGTON.W.VA.	1.979	2.103	2.316	4.400	38.434	82.506
PKB	PARKERSBURG.W.VA.	1.786	1.865	2.005	3.809	39.580	81.360
ZZV	ZANESVILLE.OHIO	1.597	1.637	1.715	3.258	40.153	81.933
ZID	INDIANAPOLIS,INDIANA	2.333	2.800	4.199	7.979	39.730	86.270

AREA NO. 8
ARTCC ZTL

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
ATL	ATLANTA,GA.	12.951	14.415	16.710	31.748	33.850	84.798
HKY	HICKORY,N.C.	6.476	7.252	8.479	16.110	35.569	81.360
MGM	MONTGOMERY.ALA.	6.834	7.652	8.932	16.970	32.131	86.517
GSP	,GREER.S.C.	4.452	4.905	5.630	10.698	34.996	82.506
MCN	MACON,GA.	4.314	4.782	5.523	10.494	32.704	83.652
BHM	BIRMINGHAM.ALA.	4.180	4.627	5.334	10.135	33.850	86.517
TYS	KNOXVILLE.TENN.	3.718	4.112	4.738	9.003	36.142	84.225
CSV	CROSSVILLE.TENN.	3.232	3.472	3.867	7.347	36.142	84.798
TCL	TUSCALOOSA.ALA.	3.382	3.655	4.092	7.776	33.277	87.663
TRI	BRISTOL,TENN.	2.058	2.203	2.446	4.648	36.715	82.506
ANB	ANNISTON.ALA.	2.849	2.980	3.197	6.074	33.850	85.944
AND	ANDERSON,S.C.	2.122	2.165	2.259	4.291	34.423	82.506
ZTL	ATLANTA,GEORGIA	2.333	2.800	4.199	7.979	33.780	84.520

AREA NO. 9
ARTCC ZMP

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
OMA	OMAHA,NEBR.	9.387	9.832	10.613	20.164	41.299	95.684
DSM	DES MOINES,IOWA	3.093	3.349	3.763	7.150	41.299	93.392
GRI	GRAND ISLAND,NEBR.	2.074	2.161	2.312	4.393	41.299	98.549
LNK	LINCOLN,NEBR.	2.470	2.535	2.659	5.051	40.726	96.830
MSP	MINNEAPOLIS,MINN.	7.227	7.943	9.067	17.228	44.736	93.392
HIB	HIBBING,MINN.	3.421	3.571	3.831	7.279	47.601	92.819
MQT	MARQUETTE,MICH.	1.999	2.109	2.297	4.365	46.455	87.663
LSE	LA CROSSE,WISC.	1.718	1.782	1.899	3.609	44.163	91.100
PLN	PELLSTON,MICH.	2.372	2.419	2.516	4.781	45.882	84.798
HON	HURON,S.D.	2.216	2.254	2.336	4.438	44.163	97.976
TVC	TRAVERSE CITY,MICH.	1.907	1.929	1.985	3.771	44.736	85.371
MCW	MASON CITY,IOWA	1.532	1.564	1.634	3.105	43.017	93.392
SSM	S.STE MARIE,MICH.	1.338	1.360	1.415	2.688	46.455	84.225
RST	ROCHESTER,MINN.	1.623	1.656	1.726	3.279	44.163	92.246
AXN	ALEXANDRIA,MINN.	1.390	1.387	1.400	2.660	45.882	95.111
EAU	EAU CLAIRE,WISC.	1.204	1.190	1.185	2.251	44.736	91.673
CMX	HOUGHTON,MICH.	1.278	1.267	1.268	2.409	47.028	88.236
PIR	PIERRE,S.D.	1.582	1.541	1.502	2.854	44.163	100.268
RWF	REDWOOD FALLS,MINN.	1.227	1.204	1.186	2.254	44.736	95.111
ABR	ABERDEEN,S.D.	1.024	.987	.952	1.809	45.309	98.549
ATY	WATERTOWN,S.D.	.999	.962	.921	1.750	45.309	97.403
ZMP	MINNEAPOLIS,MINN.	2.333	2.800	4.199	7.979	46.000	92.000

AREA NO. 10
ARTCC ZCG

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
C I	JOLIET.ILL.	17.187	19.272	22.539	42.825	41.872	88.236
FWA	FORT WAYNE.IND.	4.182	4.676	5.458	10.371	41.299	85.371
SBN	SOUTH BEND.IND.	5.149	5.554	6.220	11.817	41.872	86.517
MKE	MILWAUKEE.WISC.	4.028	4.430	5.068	9.630	43.017	87.663
RFD	ROCKFORD.ILL.	3.281	3.594	4.083	7.757	42.444	89.381
GRB	GREEN BAY.WISC.	2.965	3.202	3.585	6.812	44.736	88.236
BRL	BURLINGTON.IOWA	3.331	3.500	3.792	7.205	40.726	91.100
AUW	WAUSAU.WISC.	2.110	2.228	2.427	4.612	44.736	89.381
CID	CEDAR RAPIDS.IOWA	2.515	2.665	2.767	5.258	41.872	91.673
LNR	LONE ROCK.WISC.	2.189	2.252	2.375	4.512	43.017	89.954
ALO	WATERLOO.IOWA	1.366	1.386	1.434	2.725	42.444	92.246
OTM	OTTUMA.IOWA	1.278	1.263	1.259	2.391	41.299	92.246
ZCG	CHICAGO,ILLINOIS	2.333	2.800	4.199	7.979	41.880	87.630

AREA NO. 11
ARTCC ZME

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
MEM	MEMPHIS,TENN.	11.378	12.819	15.076	28.644	34.996	89.954
BNA	NASHVILLE,TENN.	9.364	10.629	12.603	23.947	36.142	86.517
PBF	PINE BLUFF,ARK.	5.791	6.322	7.171	13.625	34.423	91.673
MSL	MUSCLE SHOALS,ALA.	4.014	4.338	4.863	9.239	34.996	87.663
CGI	CAPE GIRARDEAU,MO.	4.477	4.799	5.306	10.082	37.288	89.381
BWG	BOWLING GREEN,KY.	2.440	2.567	2.791	5.303	37.288	86.517
DYR	DYERSBURG,TENN.	2.853	3.028	3.313	6.296	36.142	89.381
JAN	JACKSON,MISS.	2.663	2.775	2.974	5.651	32.131	89.954
MEI	MERIDIAN,MISS.	2.286	2.409	2.614	4.967	32.131	88.809
FYV	FAYETTEVILLE,ARK.	3.271	3.461	3.780	7.182	36.142	93.965
GWO	GREENWOOD,MISS.	2.157	2.175	2.226	4.229	33.277	89.954
PAH	PADUCAH,KY.	1.413	1.427	1.464	2.781	37.288	88.809
MKL	JACKSON,TENN.	1.332	1.331	1.346	2.558	35.569	88.809
HRO	HARRISON,ARK.	1.414	1.358	1.296	2.462	36.142	93.392
ZME	MEMPHIS,TENNESSEE	2.333	2.800	4.199	7.979	35.050	89.980

AREA NO. 12
ARTCC ZHU

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
HOU	HOUSTON,TEX.	[illegible].950	9.989	11.613	22.664	29.839	95.111
NEW	NEW ORLEANS,LA.	6.200	6.751	7.630	14.497	29.839	90.527
ESF	ESLER FIELD,LA.	2.403	2.567	2.837	5.390	31.558	92.246
LFT	LAFAYETTE,LA.	1.828	1.895	2.016	3.830	30.412	92.246
LFK	LUFKIN,TEX.	1.622	1.668	1.759	3.343	31.558	95.684
MCB	MCCOMB,MISS.	1.794	1.845	1.940	3.685	31.558	90.527
LCH	LAKE CHARLES,LA.	2.660	2.783	2.999	5.698	30.412	93.392
GLS	GALVESTON,TEX.	[illegible].089	1.065	1.048	1.992	29.266	95.111
SAT	SAN ANTONIO,TEX.	1[illegible].457	11.845	14.004	26.607	29.839	98.549
ALI	ALICE,TEXAS	4.656	5.087	5.776	10.974	27.548	97.976
AUS	AUSTIN,TEXAS	4.371	4.753	5.355	10.174	30.412	97.976
COT	COTULLA,TEXAS	2.342	2.423	2.572	4.886	28.693	99.122
CLL	COLLEGE STA.,TEX.	1.522	1.532	1.564	2.972	30.412	96.257
PSX	PALACIOS,TEXAS	1.493	1.457	1.429	2.716	28.693	96.257
MFE	MCALLEN,TEXAS	2.324	2.340	2.388	4.537	26.402	97.976
MOB	MOBILE,ALA.	5.563	6.219	7.252	13.778	30.985	88.236
ZHU	HOUSTON,TEXAS	2.333	2.860	4.199	7.979	29.650	95.280

AREA NO. 13
ARTCC ZFW

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
DAL	DALLAS.TEXAS	9.217	10.301	11.984	22.770	32.704	96.830
TUL	TULSA.OKLA.	7.443	8.413	9.926	18.859	36.142	95.684
TXK	TEXARKANA.ARK.	3.953	4.370	5.033	9.563	33.277	93.965
FTW	FORT WORTH,TEXAS	6.004	6.465	7.204	13.687	32.704	97.403
MLC	MCALESTER.OKLA.	2.025	2.099	2.232	4.240	34.996	95.684
MLU	MONROE,LA.	3.661	3.886	4.253	8.081	32.704	92.246
GGG	LONGVIEW.TEXAS	1.438	1.458	1.509	2.867	32.704	94.538
ELD	EL DORADO,ARK.	1.294	1.301	1.332	2.531	33.277	92.819
TYR	TYLER.TEXAS	1.179	1.159	1.148	2.182	32.131	95.684
OKC	OKLAHOMA CITY,OKLA.	10.209	11.484	13.478	25.608	35.569	97.403
MAF	MIDLAND,TEXAS	4.206	4.579	5.169	9.821	32.131	101.987
SPS	WICHITA FALLS,TEX.	3.631	3.932	4.414	8.386	33.850	98.549
ABI	ABILENE,TEXAS	3.818	4.059	4.453	8.461	32.704	99.695
LBB	LUBBOCK,TEXAS	2.411	2.559	2.805	5.330	33.850	101.987
HBR	HOBART,OKLA.	1.823	1.891	2.016	3.830	34.996	99.122
MWL	MINERAL WELLS,TEX.	2.211	2.267	2.367	4.498	32.704	97.976
INK	WINK,TEXAS	1.203	1.192	1.194	2.268	31.558	103.132
CDS	CHILDRESS.TEXAS	.976	.938	.898	1.706	34.423	100.268
ZFW	FORT WORTH.TEXAS	2.333	2.800	4.199	7.979	32.820	97.350

AREA NO. 14
ARTCC ZKC

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
STL	ST.LOUIS,MO.	8.980	10.133	11.930	22.668	39.007	90.527
MKC	KANSAS CITY,MO.	9.335	10.262	11.727	22.282	39.007	94.538
ICT	WICHITA,KANS.	6.299	6.887	7.812	14.842	37.861	97.403
DEC	VANDALIA,ILL.	4.376	13.040	5.353	10.171	40.153	88.809
SGF	SPRINGFIELD,MO.	2.546	2.698	2.949	5.603	37.288	93.392
PNC	PONCA CITY,OKLA.	2.339	2.470	2.687	5.106	36.715	96.830
COU	COLUMBIA,MO.	3.193	3.346	3.603	6.846	39.007	92.246
EMP	EMPORIA,KANS.	2.070	2.185	2.380	4.522	38.434	96.257
JLN	JOPLIN,MO.	1.991	2.099	2.284	4.340	37.288	94.538
SLN	SALINA,KANS.	2.711	2.805	2.974	5.651	39.007	97.403
VIH	VICHY,MO.	2.604	2.727	2.930	5.567	38.434	91.673
UIN	QUINCY,ILL.	1.413	1.430	1.473	2.799	40.153	91.100
GCK	GARDEN CITY,KANS.	1.545	1.558	1.592	3.[illegible]25	37.861	100.841
DDC	DODGE CITY,KANS.	1.399	1.393	1.402	2.664	37.861	99.695
RSL	RUSSELL,KANS.	1.227	1.212	1.205	2.290	39.007	98.549
CNU	CHANUTE,KANS.	1.444	1.436	1.440	2.735	37.861	95.684
GAG	GAGE,OKLA.	1.162	1.140	1.123	2.135	36.142	99.695
ZKC	KANSAS CITY,MO.	2.333	2.800	4.199	7.979	39.120	94.580

AREA NO. 15
ARTCC ZGT

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
GFK	GRAND FORKS,N.D.	2.818	2.988	3.265	6.203	48.174	96.830
JMS	JAMESTOWN,N.D.	2.033	2.053	2.107	4.003	47.028	98.549
MOT	MINOT,N.D.	1.968	1.985	2.034	3.864	48.174	101.414
BIS	BISMARCK,N.D.	1.123	1.095	1.070	2.033	47.028	100.841
DIK	DICKINSON,N.D.	.934	.890	.842	1.601	47.028	102.560
GTF	GREAT FALLS,MONT.	2.608	2.693	2.847	5.409	47.601	111.154
CTB	CUT BANK,MONT.	2.028	2.029	2.051	3.897	48.747	112.300
MSO	MISSOULA,MONT.	1.983	1.964	1.958	3.720	47.028	114.019
MLS	MILES CITY,MONT.	1.610	1.573	1.540	2.925	46.455	105.997
LWT	LEWISTOWN,MONT.	.938	.890	.833	1.583	47.028	109.435
ZGT	GREAT FALLS,MONTANA	2.333	2.800	4.199	7.979	47.480	111.350

AREA NO. 16
ARTCC ZDV

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
DEN	DENVER.COLO.	11.133	12.195	13.849	26.313	39.580	104.851
RAP	RAPID CITY.S.D.	2.664	2.810	3.051	5.796	44.163	103.132
CYS	CHEYENNE.WYO.	1.687	1.715	1.776	3.375	41.299	104.851
CDR	CHADRON.NEB.	1.308	1.305	1.318	2.505	43.017	103.132
GLD	GOODLAND.KANSAS	1.417	1.417	1.432	2.720	39.580	101.414
PUB	PUEBLO.COLO.	1.317	1.310	1.315	2.499	38.434	104.278
CPR	CASPER.WY.	1.691	1.697	1.724	3.275	43.017	106.570
GJT	GR.JUNCTION.COLO.	2.017	2.000	1.997	3.795	39.007	108.289
LBF	NORTH PLATTE.NEB.	2.000	1.989	1.997	3.793	41.299	100.841
HLC	HILL CITY.KANSAS	.954	.921	.891	1.694	39.580	99.695
FMN	FARMINGTON.N.M.	1.835	1.837	1.852	3.519	36.715	108.289
BFF	SCOTTSBLUFF.NEB.	1.286	1.263	1.243	2.362	41.872	103.705
LHX	LA JUNIA.COLO.	1.200	1.171	1.148	2.182	37.861	103.705
EGE	EAGLE.COLO.	1.141	1.110	1.083	2.057	39.580	107.143
SNY	SIDNEY.NEB.	1.039	1.005	.970	1.843	41.299	103.132
TAD	TRINIDAD.COLO.	1.460	1.402	1.337	2.541	37.288	104.278
LAR	LARAMIE.WYO.	1.025	.982	.937	1.780	41.299	105.424
AKO	AKRON.COLO.	.996	.953	.963	1.716	40.153	103.132
ZDV	DENVER.COLORADO	2.333	2.880	4.199	7.979	39.770	104.880

AREA NO. 17
ARTCC ZAB

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
PHX	PHOENIX,ARIZ.	13.871	15.382	17.708	33.646	33.277	112.300
TUS	TUCSON,ARIZ.	6.331	7.019	8.093	15.376	32.131	111.154
ELP	ELPASO,TEXAS	6.380	6.906	7.732	14.491	32.131	106.570
ABQ	ALBUQUERQUE,N.M.	5.743	6.139	6.760	12.844	34.996	106.570
AMA	AMARILLO,TEXAS	3.351	3.588	3.970	7.543	34.996	101.414
TCC	TUCUMCARI,N.M.	2.499	2.665	2.938	5.583	34.996	103.705
ROW	ROSWELL,N.M.	3.073	3.881	3.427	6.511	33.277	104.278
PRC	PRESCOTT,ARIZ.	2.767	2.766	2.793	5.307	34.423	112.300
DUG	DOUGLAS,ARIZ.	2.017	1.988	1.967	3.737	31.558	109.435
LVS	LAS VEGAS,N.M.	1.288	1.227	1.158	2.200	35.569	105.424
GUP	ZUNI PUEBLO,N.M.	1.621	1.573	1.524	2.496	40.153	88.809
DMN	DEMING,N.M.	1.045	1.005	.960	1.924	32.131	107.716
DHT	DALHART,TEXAS	.994	.949	.898	1.706	36.142	102.560
TCS	TRUTH OR CONS.,N.M.	.945	.898	.841	1.598	33.277	107.143
CNM	CARLSBAD,N.M.	1.299	1.229	1.146	2.178	32.131	104.278
ZAB	ALBUQUERQUE,N.M.	2.333	2.860	4.199	7.379	35.050	106.620

AREA NO. 18
ARTCC ZLC

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
SLC	SALT LAKE CITY	6.562	6.975	7.653	14.540	40.726	111.727
BOI	BOISE,IDAHO	4.106	4.412	4.906	9.321	43.590	116.311
BIL	BILLINGS,MONT.	1.891	1.925	1.992	3.785	45.882	108.289
BYI	BURLEY,IDAHO	2.895	2.895	2.923	5.554	42.444	114.019
RKS	ROCK SPRINGS,WYO.	1.220	1.199	1.184	2.250	41.872	108.862
IDA	IDAHO FALLS,IDAHO	1.495	1.483	1.480	2.811	43.590	112.300
TPH	TONAPAH,NEVADA	1.493	1.481	1.477	2.806	37.861	116.883
EKO	ELKO,NEVADA	1.935	1.870	1.800	3.420	40.726	115.738
WRL	WORLAND,WYO.	1.710	1.670	1.631	3.[illegible]99	44.163	107.716
SHR	SHERIDAN,WYO.	1.517	1.563	1.498	2.846	44.736	107.143
BTM	BUTTE,MONT.	1.031	.991	.949	1.[illegible]03	45.882	112.300
BKE	BAKER,ORE.	1.078	1.037	.994	1.888	44.736	118.029
RWL	RAWLINES,WYO.	.987	.943	.892	1.695	41.872	107.143
ELY	ELY,NEVADA	1.491	1.393	1.273	2.419	39.580	114.592
BZN	BOZEMAN,MONT.	1.465	1.342	1.269	2.412	45.882	111.154
LVM	LIVINGTON,MONT.	.884	.829	.762	1.448	45.882	110.581
ZLC	SALT LAKE CITY,UTAH	2.333	2.800	4.199	7.379	40.770	111.970

AREA NO. 19
ARTCC ZLA

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
LAX	LOS ANGELES,CALIF.	15.264	16.767	19.197	36.474	33.850	118.602
LAS	LAS VEGAS,NEVADA	6.979	7.630	8.639	16.414	36.142	115.165
SAN	SAN DIEGO,CALIF.	6.847	7.437	8.355	15.874	32.704	117.456
TRM	THERMAL,CALIF.	4.198	4.563	5.152	9.788	33.850	116.311
PMD	PALMDALE,CALIF.	4.061	4.351	4.819	9.157	34.423	118.029
SBA	SANTA BARBARA,CAL.	4.347	4.582	4.962	9.427	34.423	119.748
BFL	BAKERSFIELD,CALIF.	3.085	3.216	3.439	6.534	35.569	119.175
ONT	ONTARIO,CALIF.	3.062	3.221	3.476	6.605	33.850	117.456
YUM	YUMA,ARIZ.	2.127	2.217	2.373	4.508	32.704	114.592
IPL	IMPERIAL,CALIF.	2.930	3.000	3.165	6.[illegible]14	32.704	115.738
BLH	BLYTHE,CALIF.	1.378	1.370	1.375	2.613	33.850	114.592
DAG	DAGGETT,CALIF.	1.274	1.258	1.252	2.379	34.996	116.883
EED	NEEDLES,CALIF.	1.236	1.217	1.206	2.291	34.996	114.592
CDC	CEDAR CITY,UTAH	1.064	1.021	.975	1.852	37.861	112.873
BCE	BRYCE CANYON,UTAH	.942	.894	.840	1.596	37.861	112.300
ZLA	LOS ANGELES,CALIF.	[illegible].333	2.800	4.199	7.979	34.630	118.080

AREA NO. 20
ARTCC ZOA

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
SAC	SACRAMENTO,CALIF.	14.118	15.996	18.929	35.965	38.434	121.467
OAK	OAKLAND,CALIF.	15.200	16.851	19.412	36.983	37.861	122.040
FAT	FRESNO,CALIF.	5.900	6.515	7.477	14.207	36.715	119.748
MYV	MARYSVILLE ,CALIF.	2.938	3.125	3.429	6.515	39.007	121.467
ACV	ARCATA,CALIF.	1.994	2.081	2.232	4.241	41.299	124.332
RNO	RENO,NEV.	3.138	3.259	3.454	6.562	39.580	119.748
SNS	SALINAS,CALIF.	2.555	2.611	2.718	5.164	36.715	121.467
RBL	RED BLUFF,CALIF.	2.032	2.085	2.181	4.143	40.153	122.040
SCK	STOCKTON,CALIF.	2.105	2.160	2.261	4.296	37.861	121.467
PRB	PASO ROBLES,CALIF.	1.542	1.553	1.586	3.[illegible]14	35.569	120.894
LOL	LOVELOCK,NEV.	1.556	1.563	1.590	3.[illegible]21	40.153	118.602
UKI	UKIAH,CALIF.	1.737	1.749	1.782	3.386	39.007	123.186
ZOA	OAKLAND,CALIF.	2.333	2.800	4.199	7.[illegible]79	37.730	122.200

AREA NO. 21
ARTCC ZSE

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
SEA	SEATTLE,WASH.	1[illegible].460	11.435	12.981	24.664	47.601	122.[illegible]40
PDX	PORTLAND,ORE.	5.358	5.394	5.941	11.289	45.882	122.613
LMT	KLAMATH FALLS,ORE.	2.137	2.264	2.477	4.706	42.444	121.467
SFF	SPOKANE,WASH.	3.168	3.262	3.415	6.488	47.601	117.456
EUG	EUGENE,ORE.	2.228	2.310	2.453	4.660	44.163	123.186
ALW	WALLA WALLA,WASH.	3.096	3.087	3.110	5.909	45.882	118.029
YKM	YAKIMA,WASH.	[illegible].440	1.450	1.480	2.913	46.455	120.321
OTH	NORTH BEND,ORE.	1.579	1.555	1.545	2.935	43.590	124.332
MFR	MEDFORD,ORE.	1.444	1.445	1.463	2.780	42.444	122.613
EAT	WENATCHEE,WASH.	1.634	1.651	1.624	3.[illegible]85	47.601	120.321
BLI	BELLINGHAM,WASH.	1.798	1.804	1.828	3.473	48.747	122.613
HQM	HOQUIAM,WASH.	1.693	1.622	1.545	2.036	47.028	123.759
CEC	CRESCENT CITY,CAL.	1.295	1.240	1.180	2.241	41.872	124.332
EPH	EPHRATA,WASH.	1.456	1.406	1.354	2.573	47.601	119.748
RDM	REDMOND,ORE.	1.164	1.132	1.096	2.[illegible]83	44.163	120.894
DLS	THE DALLES,ORE.	.955	.910	.858	1.630	45.882	120.994
TDO	TOLEDO,WASH.	1.002	.957	.903	1.716	46.455	122.613
SIY	MONTAGUE,CALIF.	1.183	1.1[illegible]8	1.020	1.338	41.872	122.613
ZSE	SEATTLE,WASH.	2.333	2.800	4.199	7.979	47.450	122.300

CATEGORY NO.2
MILITARY TERMINALS

AREA NO. 79
ARTCC ZKC

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
P G		1.000	1.000	1.000	1.000	44.650	73.450
C F		1.000	1.000	1.000	1.000	42.300	72.530
P M		1.000	1.000	1.000	1.000	43.080	70.820
R F		1.000	1.000	1.000	1.000	43.230	75.420
N Z		1.000	1.000	1.000	1.000	43.880	69.930
N O		1.000	1.000	1.000	1.000	41.580	71.420
L Z		1.000	1.000	1.000	1.000	46.800	67.880
F H		1.000	1.000	1.000	1.000	41.650	70.630
FFO		1.000	1.000	1.000	1.000	39.820	84.050
GUS		1.000	1.000	1.000	1.000	40.650	86.150
MTC		1.000	1.000	1.000	1.000	42.820	82.830
S W		1.000	1.000	1.000	1.000	46.550	87.380
I R		1.000	1.000	1.000	1.000	46.250	84.470
O C		1.000	1.000	1.000	1.000	44.470	83.370
S A		1.000	1.000	1.000	1.000	47.620	117.650
N W		1.000	1.000	1.000	1.000	48.350	122.670
T M		1.000	1.000	1.000	1.000	47.150	122.480
N C		1.000	1.000	1.000	1.000	36.330	119.950
V G		1.000	1.000	1.000	1.000	34.750	120.570
RIV		1.000	1.000	1.000	1.000	33.900	117.250
S D		1.000	1.000	1.000	1.000	34.100	117.250
NZJ		1.000	1.000	1.000	1.000	33.680	117.720
S F		1.000	1.000	1.000	1.000	38.070	122.520
M R		1.000	1.000	1.000	1.000	37.370	120.570
B B		1.000	1.000	1.000	1.000	39.120	121.430
N N		1.000	1.000	1.000	1.000	37.320	122.050
SUU		1.000	1.000	1.000	1.000	38.270	121.930
B M		1.000	1.000	1.000	1.000	30.630	88.070
A X		1.000	1.000	1.000	1.000	31.320	92.550
DLF		1.000	1.000	1.000	1.000	29.370	100.780
L D		1.000	1.000	1.000	1.000	27.530	99.470
NCG		1.000	1.000	1.000	1.000	29.830	90.020
NCP		1.000	1.000	1.000	1.000	27.680	97.280
B M		1.000	1.000	1.000	1.000	30.200	97.670
BTX		1.000	1.000	1.000	1.000	30.400	88.920
N I		1.000	1.000	1.000	1.000	27.500	97.800
NTR		1.000	1.000	1.000	1.000	28.370	97.670
TIK		1.000	1.000	1.000	1.000	35.400	97.600

[illegible]	1.000	1.000	1.000	1.000	34.650	99.270
[illegible]	1.000	1.000	1.000	1.000	33.970	98.480
[illegible]	1.000	1.000	1.000	1.000	33.600	102.130
[illegible]	1.000	1.000	1.000	1.000	32.500	93.680
[illegible]	1.000	1.000	1.000	1.000	32.430	99.850
CVS	1.000	1.000	1.000	1.000	34.380	103.320
H[illegible]N	1.000	1.000	1.000	1.000	32.850	106.080
D[illegible]A	1.000	1.000	1.000	1.000	32.170	110.880
C[illegible]D	1.000	1.000	1.000	1.000	33.180	111.070
L[illegible]F	1.000	1.000	1.000	1.000	33.830	112.370
M[illegible]C	1.000	1.000	1.000	1.000	40.600	73.930
W[illegible]I	1.000	1.000	1.000	1.000	40.030	74.600
D[illegible]V	1.000	1.000	1.000	1.000	39.130	75.470
N[illegible]K	1.000	1.000	1.000	1.000	38.300	76.420
NTU	1.000	1.000	1.000	1.000	36.720	76.030
N[illegible]T	1.000	1.000	1.000	1.000	34.900	76.880
G[illegible]H	1.000	1.000	1.000	1.000	35.330	77.970
P[illegible]H	1.000	1.000	1.000	1.000	35.150	79.020
R[illegible]A	1.000	1.000	1.000	1.000	44.150	103.100
C[illegible]S	1.000	1.000	1.000	1.000	38.820	104.700
MTH	1.000	1.000	1.000	1.000	48.420	101.300
GFK	1.000	1.000	1.000	1.000	47.930	97.080
L[illegible]F	1.000	1.000	1.000	1.000	34.920	92.150
H[illegible]P	1.000	1.000	1.000	1.000	36.670	87.500
C[illegible]I	1.000	1.000	1.000	1.000	33.630	88.450
S[illegible]M	1.000	1.000	1.000	1.000	32.350	87.180
L[illegible]F	1.000	1.000	1.000	1.000	32.350	85.000
MYF	1.000	1.000	1.000	1.000	32.300	86.400
W[illegible]B	1.000	1.000	1.000	1.000	32.700	83.650
MYR	1.000	1.000	1.000	1.000	33.680	78.930
N[illegible]A	1.000	1.000	1.000	1.000	30.350	87.320
P[illegible]M	1.000	1.000	1.000	1.000	30.070	85.580
V[illegible]D	1.000	1.000	1.000	1.000	30.970	83.200
S[illegible]C	1.000	1.000	1.000	1.000	33.970	80.480
N[illegible]C	1.000	1.000	1.000	1.000	32.480	80.720
N[illegible]B	1.000	1.000	1.000	1.000	31.580	84.120
MCF	1.000	1.000	1.000	1.000	27.850	82.500
M[illegible]O	1.000	1.000	1.000	1.000	28.450	81.300
C[illegible]F	1.000	1.000	1.000	1.000	28.230	80.600
H[illegible]T	1.000	1.000	1.000	1.000	25.370	80.400
N[illegible]X	1.000	1.000	1.000	1.000	24.580	81.680

CATEGORY NO.3
AFTN IN MAINLAND

AREA NO. 2
APICC ZK[illegible]

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
1 7	MP1 7	1[illegible].940	19.128	22.954	43.[illegible]12	25.450	80.150
2 6	MP2 6	1[illegible].[illegible]50	18.060	21.672	41.177	25.450	80.150
3 4	MP3 4	1[illegible].772	15.326	18.392	34.944	18.290	66.080
4 5	MP4 5	1[illegible].410	12.492	14.990	28.482	18.290	66.080
5 3	MP5 3	17.935	21.522	25.826	49.[illegible]70	40.440	73.120
6 3	MP6 3	1[illegible].827	17.792	21.351	40.567	40.440	73.120
7 7	MP7 7	[illegible].538	10.246	12.295	23.360	40.440	73.120
8 4	MP8 4	1[illegible].[illegible]30	12.036	14.443	27.442	40.440	73.120
9 6	MP9 6	1[illegible].237	17.048	20.458	38.870	40.440	73.120
[illegible] 6	MP13 6	[illegible].869	11.843	14.211	27.[illegible]02	37.380	122.240
1[illegible] 3	MP14 3	[illegible].058	10.870	13.044	24.783	37.430	122.110
1[illegible] 3	MP15 3	1[illegible].843	13.012	15.614	29.666	33.570	118.220
F T	FORT WORTH,TEXAS	[illegible].940	4.728	5.674	10.780	32.820	97.350
W C	WASHINGTON,D.C.	[illegible].619	3.132	3.758	7.141	38.850	77.030
B S	BOSTON,MASS.	1.990	2.388	2.866	5.445	42.930	71.430
CHI	CHICAGO,ILLINOIS	1.640	1.968	2.362	4.487	41.880	87.630
ATL	ATLANTA,GEORGIA	1.290	1.548	1.858	3.529	33.780	84.520

AREA NO. 1
ARTCC ZKC

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
OOI	HKMIAYF	23.581	28.297	33.957	64.518	25.450	80.150
YM1	KMIAYM1	35.677	42.812	51.375	97.612	25.450	80.150
YM2	KMIAYM2	35.753	42.904	51.484	97.820	25.450	80.150
SJY	MJSJY	19.397	23.276	27.932	53.070	18.290	66.080
JZO	MJSJZO	19.663	23.596	28.315	53.798	18.290	66.080
JYS	MJSJYS	39.789	47.747	57.296	108.863	18.290	66.080
YM1	MJSJYM1	33.386	40.063	48.076	91.344	18.290	66.080
YM2	MJSJYM2	29.135	34.962	41.954	79.713	18.290	66.080
UGM	MUGM	5.633	6.760	8.112	15.412	19.590	75.100
KYF	KJFKYF	19.822	23.786	28.544	54.233	40.440	73.120
YM1	KJFKYM1	7.121	8.545	10.254	19.483	40.440	73.590
YM2	KJFKYM2	1.922	2.306	2.768	5.259	40.440	73.590
LIZ	KLIZ	4.658	5.590	6.708	12.744	46.570	67.530
WRI	KWRI	4.659	5.591	6.709	12.747	40.000	74.380
CYC	KNYCYC	3.298	3.958	4.749	9.023	40.410	74.010
CEA	KDPCEA	2.550	3.060	3.672	6.977	35.460	78.380
AWN	KAWN	16.353	19.624	23.548	44.742	32.460	97.270
UYU	KHOUYU	1.120	1.344	1.613	3.064	29.460	92.220
BC1	KWBC1	31.174	37.409	44.891	85.292	38.510	76.560
BC2	KWBC2	29.167	35.000	42.000	79.801	38.510	76.560
OYN	KSFOYN	3.206	3.847	4.617	8.772	37.380	122.240

AREA NO.
ARICC ZAN

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
F.B.	PANCYFFS	1[illegible].655	16.386	19.663	37.360	61.130	149.540
CYN	PANCYN	[illegible].448	10.138	12.165	23.114	61.130	149.540
CYA	PANCYA	1[illegible].210	12.252	14.702	27.935	61.130	149.540
AFI	PANCYAFI	[illegible].695	3.234	3.881	7.374	61.130	149.540
MAS	PANCYMAS	1[illegible].486	13.783	16.540	31.426	61.130	149.540
SIN	PANCYSIN	1[illegible].219	18.263	21.915	41.639	61.130	149.540
SAG	PANCYSAG	1[illegible].470	17.364	20.837	39.590	61.130	149.540
CZO	PANCZO	6.373	7.648	9.177	17.437	61.130	149.540
CZZ	PANCZZ	3.486	4.183	5.020	9.538	61.130	149.540
NYA	PAENYA	2.439	2.927	3.512	6.673	60.330	151.160
RYF	PABRYF	4.273	5.128	6.153	11.691	71.180	156.470
IYF	PANIYF	1.527	1.832	2.199	4.178	61.350	159.320
EYF	PAREYF	1.528	1.834	2.200	4.181	60.480	161.450
LYF	PADLYF	1.529	1.835	2.202	4.183	59.030	158.280
LYF	PAILYF	1.530	1.836	2.203	4.186	59.450	154.550
NYF	PAENYF	1.531	1.837	2.205	4.189	60.330	151.160
OYF	PAHOYF	1.532	1.838	2.206	4.192	59.390	151.330
DYF	PAWDYF	1.533	1.840	2.208	4.194	57.470	152.240
DYX	PAWDYX	1.534	1.841	2.209	4.197	57.470	152.240
HYX	PANHYX	1.535	1.842	2.210	4.200	57.450	152.320
NYF	PAKNYF	1.536	1.843	2.212	4.202	58.420	156.400
DRV	PACDRV	1.537	1.844	2.213	4.205	55.120	162.420
DFT	PACDFT	1.538	1.846	2.215	4.208	55.120	162.420
DYF	PACDYF	1.539	1.847	2.216	4.211	55.120	162.420
KRV	PADKRV	1.540	1.848	2.218	4.213	51.450	176.450
KYX	PADKYX	1.541	1.849	2.219	4.216	51.450	176.450
YYX	PASYYX	1.542	1.850	2.220	4.219	52.430	174.070
RYX	PAFRYX	1.621	1.945	2.334	4.435	61.140	149.540
DYD	PAEDYD	1.622	1.946	2.336	4.438	61.140	149.540
DYX	PAEDYX	1.623	1.948	2.337	4.441	61.140	149.540
DYC	PAEDYC	1.624	1.949	2.339	4.443	61.140	149.540
VYF	PACVYF	1.625	1.950	2.340	4.446	60.330	145.450
AYF	PAYAYF	1.626	1.951	2.341	4.449	59.330	139.440
NYF	PAJNYF	1.627	1.952	2.343	4.451	58.180	134.250
IYF	PASIYF	1.628	1.954	2.344	4.454	57.030	135.200
TYF	PAKTYF	1.629	1.955	2.346	4.457	55.210	131.390
TYF	PANTYF	1.630	1.956	2.347	4.460	55.040	131.330
OYF	PAAQYF	1.709	2.051	2.461	4.676	61.360	149.070
OYO	PAAQYO	1.710	2.052	2.462	4.679	61.360	149.070
WYF	PAFWYF	1.711	2.053	2.464	4.681	62.310	153.540

[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Y	.67	.94[illegible]	[illegible]9	4.[illegible]3	61.1[illegible]	149.[illegible]40
VYI	PACVYI	1.625	1.950	2.[illegible]0	4.446	60.330	145.450
AYI	PAYAYI	1.626	1.951	2.341	4.449	59.330	139.440
NYI	PAJBYI	1.627	1.952	2.343	4.451	58.180	134.250
I[illegible]	PA[illegible]IYI	1.628	1.954	2.344	4.454	57.030	135.200
I[illegible]	[illegible]AKIYI	1.629	1.955	2.346	4.457	55.210	131.390
TYF	PANTYF	1.630	1.956	2.347	4.460	55.040	131.330
QYF	PAAQYF	1.709	2.051	2.461	4.676	61.360	149.070
QYQ	PAAQYQ	1.710	2.052	2.462	4.679	61.360	149.070
WYF	PAFWYF	1.711	2.053	2.464	4.681	62.310	153.540
CYF	PAMCYF	1.712	2.054	2.465	4.684	62.580	155.360
NYF	PAUNYF	1.713	2.056	2.467	4.687	63.520	160.470
MYF	PAOMYF	1.714	2.057	2.468	4.690	64.300	165.250
AYF	PAGAYF	1.715	2.058	2.470	4.692	64.440	156.560
AYF	PATAYF	1.716	2.059	2.471	4.695	65.100	152.040
TYF	PABTYF	1.717	2.060	2.472	4.698	64.550	151.420
TYF	PAOTYF	1.718	2.062	2.474	4.700	66.540	162.350
KYF	PATKYF	2.024	2.429	2.915	5.538	62.200	150.060
KYF	PAGKYF	2.025	2.430	2.916	5.540	62.160	145.230
YYF	CYXYYF	2.026	2.431	2.917	5.543	60.410	135.080
AYF	CYMAYF	2.027	2.432	2.919	5.546	60.410	135.080
AYF	CYDAYF	2.028	2.434	2.920	5.549	60.410	135.080
RYF	PAORYF	2.029	2.435	2.922	5.551	62.580	142.000
IYF	PABIYF	2.030	2.436	2.923	5.554	64.100	145.550
GYX	PABGYX	2.031	2.437	2.925	5.557	64.100	145.550
IYX	PAEIYX	2.032	2.438	2.926	5.560	64.350	147.000
EYF	PANEYF	2.033	2.440	2.928	5.562	64.350	149.200
BYX	PAFBYX	2.034	2.441	2.929	5.565	64.490	147.400
AYM	PAFAYM	2.035	2.442	2.930	5.568	64.510	147.430
AYF	PAFAYF	2.036	2.443	2.932	5.570	64.510	147.430
AYR	PAFAYR	2.037	2.444	2.933	5.573	64.510	147.430
AJA	PAFAJA	2.038	2.446	2.935	5.576	64.510	147.430
AZQ	PAFAZQ	2.039	2.447	2.936	5.579	64.510	147.430
CYF	PASCYF	2.040	2.448	2.938	5.581	70.080	143.380

AREA NO. 2
ARTCC ZAN

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
1.2 MRI.12		16.651	19.981	23.977	45.557	149.540	89.040

AREA NO. 1
ARTCC ZHN

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
00-0	PHNLYA	16.543	19.852	23.822	45.262	21.190	157.520
LZO	PHNLZO	11.981	14.377	17.253	32.780	21.190	157.520
KYM	PHIKYM	4.198	5.038	6.045	11.486	21.220	158.000
LYY	PHNLYY	3.190	3.828	4.594	8.728	21.190	157.520
AYX	PHNAYX	6.182	7.418	8.902	16.914	21.170	158.060
GYX	PHNGYX	6.183	7.420	8.904	16.917	21.170	158.060
LYC	PHNLYC	8.693	10.432	12.518	23.784	21.170	158.060
LYN	PHNLYN	26.401	31.681	38.017	72.233	21.190	157.520
LYF	PHNLYF	2.231	2.677	3.213	6.104	21.190	157.520
HLI	PHLI	2.232	2.678	3.214	6.107	22.030	159.300
HZO	PHZHZO	2.233	2.680	3.216	6.109	21.160	157.490
HOG	PHOG	2.234	2.681	3.217	6.112	20.480	156.200
HTO	PHTO	2.235	2.682	3.218	6.115	19.440	155.050
LYS	PHNLYS	2.236	2.683	3.220	6.118	21.190	157.520
LYM	PHNLYM	2.333	2.800	3.360	6.383	21.190	157.520
UYF	NSTUYF	8.998	10.798	12.957	24.619	14.160	70.430
MOY	PMOY	3.543	4.252	5.102	9.694	28.150	177.250
KWA	PKWA	27.892	33.470	40.164	76.313	9.150	167.300
MYF	PGUMYF	14.313	17.176	20.611	39.160	13.300	144.400

AREA NO. 2
ARTCC ZHN

ID	LOCATION	YEAR75	YEAR77	YEAR80	YEAR84	LATITUDE	LONGITUDE
1[illegible]7	MP11[illegible]7	1[illegible].810	15.372	18.446	35.[illegible]48	21.190	157.520
1 3	MP12[illegible]3	11.126	13.351	16.021	30.441	13.300	144.400
1[illegible]4	MP16[illegible]	1[illegible].828	17.794	21.352	40.569	21.190	157.520

APPENDIX I

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